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INFLUENCE OF VARIETY, LOCATION, FERTILIZER, AND STORAGE ON THE ASCORBIC ACID CONTENT OF POTATOES GROWN IN NEW YORK STATE[1]

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INTRODUCTION

In connection with a long-time research program designed to improve the potato industry in New York State (*22*),[2] the ascorbic acid content of several varieties of potatoes (*Solanum tuberosum* L.) grown in different parts of the State was determined, and the effect of soil reaction, fertilizer, temperature, and period of storage on the ascorbic acid content of the raw potato was studied. Incidental to studies of the culinary quality of these potatoes, some determinations were made of the ascorbic acid content of cooked potatoes. Observations made during three consecutive seasons (1937 to 1939) are reported here.

REVIEW OF LITERATURE

The factors reported as influencing the ascorbic acid content of foods have been summarized by the American Medical Association (*1*). The observations on potatoes which have a bearing on the present investigation will be mentioned briefly.

Varietal differences in ascorbic acid content of potatoes have been reported by a number of investigators (*3, 4, 6, 8, 9, 16, 18, 23, 24*). Ijdo (*4*) found variations up to 60 percent between varieties of potatoes, but not more than 10 percent within a variety. Esselen, Lyons, and Fellers (3) stated that although they found varietal differences, in many cases the difference within a variety was greater than that between varieties.

Decreases of from 50 to 70 percent in ascorbic acid content of potatoes stored from 6 to 12 months have been reported (*3, 6, 12, 13, 15, 17, 21, 23, 24*). Mayfield et al. (*9*) observed that the loss of ascorbic acid was greater when potatoes were stored in a cool, damp cellar (37° to 46° F.) than when stored in a warm, dry cellar (55° to 60°). The initial loss may be very rapid, as indicated by the studies of Scheunert et al. (*15*) and Olliver (*10*).

Although the location in which the vegetable is grown and the season have been shown to affect the vitamin C content of some vegetables, few observations have been reported on potatoes. Thiessen (*21*) observed that the vitamin C content of Bliss Triumph potatoes was fairly constant for the crops for 4 different years, the potatoes

[1] Received for publication August 10, 1942. The manuscripts from which these data were taken were presented to the faculty of the Graduate School of Cornell University in partial fulfillment of the requirements for the degree of master of science by Lola T. Dudgeon in 1938 and by Katherine Johnson in 1940.

[2] Italic numbers in parentheses refer to Literature Cited, p. 62.

grown on dry land containing slightly more vitamin C than those grown on irrigated land. Esselen, Lyons, and Fellers (*3*) tested several varieties of potatoes grown in different sections of the country, and found no significant differences in their ascorbic acid content. Wachholder and Nehring (*24*) concluded, however, that some factor associated with location is more important with respect to vitamin C than is either fertilizer or variety.

Evidence as to the effect of fertilizers on the vitamin C content of potatoes is conflicting. Illyuviev and Ulanova (*5*) reported that nitrogen and potassium fertilizers increase the vitamin C content of potatoes. Scheunert and Reschke (*14*), however, after studying the vitamin C content of vegetables, including potatoes fertilized with farmyard manure and with manure plus nitrogen, phosphorus, and potassium fertilizers, concluded that the differences between individual specimens of the same plant were greater than those between specimens differently fertilized.

Ott (*11*) studied potatoes from field experiments in which the soils had been fertilized with mineral fertilizers containing various combinations of nitrogen, potassium, phosphorus, and calcium, with and without the addition of manure. He reported that fertilizing with nitrogen and phosphorus increased the vitmain C content of potatoes whereas potassium and calcium decreased it. The potatoes used in his experiments, however, had been kept at room temperature from the time of harvest, in October, until December before they were tested. At that time the ascorbic acid values ranged from 1.7 to 3.9 mg. per 100 gm. These low values suggest that storage had influenced the ascorbic acid content much more than fertilizer.

Wachholder and Nehring (*23*) found that ascorbic acid content was often higher when a mineral fertilizer was used than when stable manure was employed; however, as a result of later experiments (*24*), these authors concluded that fertilizer was of less importance than was location in its effect on the vitamin C content of potatoes.

Lyons and Fellers (*7*) found that the addition of certain minor elements (lead, boron, zinc, manganese, magnesium, mercury, and cobalt) to soils of varying acidity had little or no effect on the ascorbic acid content of potatoes grown on soils to which a complete fertilizer had been added.

EXPERIMENTAL PROCEDURES

The potatoes used in this study were supplied by the Department of Vegetable Crops of the New York State College of Agriculture. All stocks were practically disease-free.

Eight potatoes from each lot in the 1938 and 1939 crops were analyzed; in 1937 only four from each lot were tested.

STORAGE

When potatoes grown in various parts of the State were received in Ithaca, they were put into storage at 40° F. unless the effect of other storage temperatures was being investigated. A variable number of days elapsed between harvest and storage of the potatoes grown in the different localities, but this period at uncontrolled temperature was approximately the same for all varieties raised in a given locality in one year. All potatoes were tested within 2 days after they were

taken out of storage. Between time of removal from storage and analysis, they were kept in a refrigerator at a temperature of 40°. Since the period of storage influences the vitamin C content, the lots of potatoes to be compared were either analyzed during a relatively short time, or potatoes were tested from the several lots in rotation, two at a time, until the testing was finished.

SAMPLING

After preliminary experiments with samples of cortex and medulla, lengthwise half slices and crosswise half slices, a crosswise center half slice from the pared potato was chosen for analysis. The paring, about one-sixteenth inch thick, was removed by means of a slit vegetable knife, and a 10-gm. sample was cut with a stainless-steel paring knife. The samples were immediately covered with the acid extracting medium to minimize opportunity for oxidation. Since the completion of this study, Rolf (*12*) has reported that the relative distribution of ascorbic acid between stem and bud end differed in Green Mountain, Irish Cobbler, and immature Chippewa potatoes, and was subject to continuous change throughout storage. Rolf's graphs showing these changes during storage, however, indicate that changes in the ascorbic acid content of the whole tuber, as indicated by an average of values obtained from stem end, bud end, and side pieces, is reflected in a change in ascorbic acid content of the side pieces. These latter correspond approximately to the center half slices chosen as the samples in this study.

Determinations on such samples from 52 old and 24 new potatoes showed, as Olliver (*10*), Rolf (*12*), and Esselen, Lyons, and Fellers (*3*) have reported, that there was no relation between ascorbic acid content of potatoes and tuber size. Hence no attempt was made to select potatoes of uniform size for analysis.

COOKING

About 1 kg. of potatoes was washed, dried, and pared with a slit paring knife which gave a fairly uniform paring, about one-sixteenth inch thick. The pared potatoes were weighed, washed in a quart of cold water for about 30 seconds, and drained while a thermometer was being inserted into one potato of the lot. The potatoes were then put into a 5-quart enameled pan containing actively boiling, unsalted water. Two grams of water for each gram of unpared potato had been weighed before heating. The potatoes were cooked, covered, to an internal temperature of 97.8° C. (208° F.). After draining, the entire lot of cooked potatoes was mashed with an ordinary wire potato masher. Vitamin C determinations were made on 10-gm. samples in a manner similar to that described for the raw potatoes, except that it was unnecessary to use sand in grinding.

DETERMINATION OF ASCORBIC ACID

Reduced ascorbic acid was determined by a modification of the method of Bessey and King (*2*). After preliminary tests with several acid solutions, a 2-percent solution of sulfuric acid, to which 2 percent of metaphosphoric acid was added, was chosen as the extracting medium. Values for blanks were always low, and there was no indication that sulfuric acid was unsuitable for this use, as suggested by the American Medical Association (*1*).

The samples were ground in a glass mortar with acid-washed sand and portions of the extracting medium. Three extractions were made, with approximately 30 ml. of acid solution each time; the material obtained was centrifuged, and the combined extracts made up to volume in a 100-ml. flask.

Aliquot portions were titrated against a solution of sodium 2, 6-dichlorobenzenoneindophenol which was standardized against a solution of synthetic ascorbic acid. Reduced ascorbic acid only was determined, since preliminary tests showed no marked difference between extracts treated with hydrogen sulfide and untreated extracts; hence, the amount of ascorbic acid in the reversibly oxidized form was considered to be negligible.

RESULTS AND DISCUSSION

EFFECT OF VARIETY ON ASCORBIC ACID CONTENT OF RAW POTATOES

Material for this part of the study was taken from replicated variety-yield tests. The seed was from the same source and the potatoes had previously been stored under identical conditions.

Seven varieties of potatoes—Irish Cobbler, Chippewa, Earlaine, Green Mountain, Houma, Katahdin, and Warba—grown in different locations in the State in the seasons of 1937, 1938, and 1939, were analyzed for vitamin C. All of these varieties, except Warba, were grown in Tompkins and Suffolk Counties in all three seasons; all varieties were grown in Wayne County in the seasons of 1937 and 1938, and Warba was grown in Tompkins County in these two seasons only. All varieties were grown in Genesee County in 1939. In addition, the following varieties were tested: Sebago, grown in Tompkins and Suffolk Counties in 1938 and 1939, in Wayne County in 1938 only, and in Genesee County in 1939 only; Pioneer Rural, grown in Wayne and Tompkins Counties in 1938, and in Genesee County in 1939; Russet Rural, grown in Wayne and Tompkins Counties in 1938, and in Genesee and Tompkins Counties in 1939; and Mohawk (U. S. Department of Agriculture Seedling 46000), grown in Suffolk County in 1938 and 1939.

With the exception of Katahdin, all varieties grown in different locations in the three seasons were mature when harvested. In 1937 and 1938, tubers of the variety Katahdin were nearly mature. In these years no records were kept of the dates of maturity, and early-maturing varieties remained in the ground for some time before harvest. In 1939, in Tompkins and Genesee Counties, the several varieties were harvested soon after they matured, and were analyzed for ascorbic acid content within a few days after harvest (table 1). Of the other varieties tested, all were mature except Russet Rural and Pioneer Rural, grown in Tompkins County in 1938, which were nearly mature when harvested, and the potatoes of the variety Sebago, grown in Tompkins County in 1938, which were immature.

Information concerning the soil in which the potatoes were grown and the fertilizer treatment used in each location is given in the footnotes to table 1. Although it is convenient to indicate the location by the name of the county, it should not be inferred that the potatoes grown on a given farm are representative of all potatoes grown in the county.

TABLE 1.—*Mean ascorbic acid values for varieties of potatoes grown in different locations, during 3 seasons* [1]

Location and year	Date of harvest	Period of testing (after harvest)	Mean ascorbic acid value for—								
			Katahdin	Irish Cobbler	Chippewa	Earlaine	Warba	Houma	Green Mountain	Sebago	All varieties
Tompkins:		*Days*	*Mg.*	*Mg.*	*Mg.*	*Mg.*	*Mg.*	*Mg.*	*Mg.*	*Mg.*	*Mg.*
1937 [2]	Oct. 26	86–103	13.2	13.8	11.8	13.3	11.6	15.3	14.9	.....	13.2
1938 [3]	Sept. 28	13– 50	29.3	19.5	20.3	25.0	20.8	25.5	21.6	19.3	22.6
1939 [3]	Sept. 8 / Oct. 3 / Nov. 1	3– 7	28.1	40.3	29.6	45.3	.....	40.9	19.9	26.6	32.9
Suffolk:											
1937 [4]	Sept. 22	59– 77	16.3	10.8	7.4	9.0	10.1	15.3	15.0	.....	11.4
1938 [4]	Sept. 5	29– 71	14.8	12.0	8.6	14.5	10.3	13.8	11.0	12.3	12.2
1939 [4]	Sept. 5	13– 15	27.9	21.3	22.8	24.5	.....	26.8	21.0	25.8	24.3
Wayne:											
1937 [5]	Sept. 1	119–125	13.4	5.8	8.7	6.1	7.5	11.8	9.9	.....	9.2
1938 [6]	Oct. 5	10– 45	19.8	14.1	10.4	17.5	15.6	16.1	16.5	16.5	15.8
Genesee, 1939 [7]	Sept. 8 / Sept. 26	3– 8	36.6	30.3	22.3	33.4	.....	25.7	22.1	27.5	28.3

[1] For 1937 each mean for a variety within a county represents 4 tubers; for 1938 and 1939 each such mean represents 8 tubers. The values given are in milligrams per 100 gm. of raw potato.
[2] Grown on Dunkirk silt loam soil of heavy type; 1,000 pounds of 5–10–5 fertilizer added per acre.
[3] Grown on Lordstown stony silt loam soil; 1,000 pounds of 5–10–5 fertilizer added per acre.
[4] Grown on Sassafras silt loam soil; 2,000 pounds of 5–10–5 fertilizer added per acre.
[5] Grown on muck soil; 1,800 pounds of 4–8–12 fertilizer added per acre.
[6] Grown on muck soil; 2,250 pounds of 5–8–10 fertilizer added per acre.
[7] Grown on muck soil; 800 pounds of 8–16–16 fertilizer added per acre.

In 1937, the ascorbic acid determinations on these lots were made between December 17 and January 6; in 1938, between October 5 and November 29; and in 1939, between September 11 and November 7. The mean ascorbic acid values for a given variety varied from year to year, being lower when the storage period was longer. The mean ascorbic acid values for the varieties on which the most data were obtained are shown in table 1. The data were treated by analysis of variance, the data for each year being analyzed separately and the data for those varieties grown in the same locations in 1938 and 1939, together. Although considerable variation was observed between tubers of a given variety, for one location and year, there is a mathematically significant difference in vitamin C content between varieties, for the odds are greater than 99:1 against the chance occurrence of so great a difference.

The differences between means of certain varieties grown in three locations in 1938 and 1939 are given in table 2. Only those comparisons which seem most likely to represent real differences are shown. With few exceptions, differences between varieties being compared are in the same direction for both years and all locations. When data for varieties grown in Tompkins and Suffolk Counties in 1938 and 1939 were analyzed together, all the differences included in table 2 were significant at the 1-percent level. For these locations and years, the varieties Katahdin, Earlaine, and Houma tended to have high ascorbic acid values, whereas the ascorbic acid values for Chippewa and Green Mountain tended to be low, and those for Sebago and Cobbler, intermediate. Although the variety Warba was not grown in 1939, the most consistent differences between Warba and other varieties grown in 1938 are included in table 2. Mean values for Warba for 1937

TABLE 2.—*Differences between means of ascorbic acid values of certain varieties of potatoes grown in 1938 and 1939* [1]

Comparison of varieties	Differences between means of varieties within a county						Differences between means of varieties, 3 locations, within a year		Differences between means of varieties when 2 counties for 2 years were analyzed together		
	Tompkins		Suffolk		Wayne	Genesee			Varieties grown in 2 counties in 1 year		Varieties grown in 2 counties in 2 years
	1938	1939	1938	1939	1938	1939	1938	1939	1938	1939	1938 and 1939
	Mg.	*Mg.*	*Mg.*	*Mg.*	*Mg.*	*Mg.*	*Mg.*	*Mg.*	*Mg.*	*Mg.*	*Mg.*
Katahdin:											
Chippewa	−9.0**	[2] (+1.5)	−6.2**	−5.1	−9.4**	−14.3**	−8.2**	− 6.0**	−7.6**	− 1.8	−4.7**
Green Mountain	−7.7**	−8.2**	−3.8	−6.9	−3.3	−14.5**	−5.0**	− 9.9**	−5.7**	− 7.5**,	−6.6**
Sebago	−10.0**	−1.5	−2.5	−2.1	−3.3	− 9.1**	−5.3**	− 4.3	−6.2**	− 1.8	−4.0**
Warba	−8.5**		−4.5		−4.2		−5.8**				
Irish Cobbler:											
Earlaine	+5.5**	+5.0	+2.5	+3.2	+3.4	+ 3.1	+3.8**	+ 3.7	+4.0	+ 4.1	+4.0**
Houma	+6.0**	+ .6	+1.8	+5.5	+2.0	[2] (− 4.6)	+3.3**	+ .4	+3.9	+ 3.0	+3.4**
Green Mountain	[2] (+2.1)	−20.4**	−1.0	− .3	[2] (+2.4)	− 8.2**	+1.1	− 9.7**	+ .5	−10.3**	−4.9**
Chippewa:											
Earlaine	+4.7	+15.7**	+5.9**	+1.7	+7.1**	+11.1**	+5.9**	+ 9.5**	+5.4**	+ 8.7**	+7.0**
Houma	+5.2	+11.3**	+5.2	+4.0	+5.7**	+ 3.4	+5.4**	+ 6.2**	+5.3**	+ 7.6**	+6.4**
Earlaine:											
Green Mountain	−3.4	−25.4**	−3.5	−3.5	−1.0	−11.3**	−2.7	−13.4**	−3.5	−14.4**	−8.9**
Sebago	−5.7**	−18.7**	−2.2	+1.3	−1.0	− 5.9	−3.0	− 7.8**	−4.0	− 8.7**	−6.3**
Warba	−4.2		−4.2		−1.9		−3.5**				
Houma:											
Green Mountain	−3.9	−21.0**	−2.8	−5.8	+.4	− 3.6	−2.2	−10.1**	−3.4	−13.3**	−8.3**
Sebago	−6.2**	−14.3**	−1.5	−1.0	[2] (+.4)	[2] (+ 1.8)	−2.5	− 4.5	−3.9	− 7.6**	−5.7**
Warba	−4.7		−3.5		− .5		−3.0				
Green Mountain:											
Sebago	[2] (−2.3)	+6.7	+1.3	+4.8	[2] (0)	+ 5.4	− .3	+ 5.6**	− .5	+ 5.7**	+2.6**
Least difference [3]	5.4**	8.1**	5.4**	8.1**	5.4**	8.1**	3.1**	4.7**	4.6**	4.6**	3.3**

[1] Each mean for a variety within a county represents 8 tubers; the values given are in milligrams per 100 gm. of raw potato.
[2] Values within parentheses are exceptions.
[3] Least difference between mean values required for odds of 99 : 1 against the chance occurrence of the difference.
**Significant at the 1-percent level.

(table 3) and 1938 (table 2) were consistently lower than those for Katahdin and Houma. When means of varieties for all locations within one year are compared, differences between Katahdin and Warba are significant at the 1-percent level for both 1937 and 1938, and differences between Houma and Warba are significant at the 1-percent level for 1937.

Since the potatoes were not grown, in all cases, in the same location within the county in 1937 as in 1938 and 1939, and since four tubers only from each lot were analyzed in 1937, the differences which appeared to be most significant for the 1937 crop are shown separately in table 3. In most instances the data obtained in 1937 support those

TABLE 3.—*Differences between means of ascorbic acid values of different varieties of potatoes grown in 3 locations in 1937* [1]

Comparison of varieties	Difference between means of varieties within a county			Difference between means of varieties in all counties
	Tompkins	Suffolk	Wayne	
	Mg.	*Mg.*	*Mg.*	*Mg.*
Katahdin:				
Irish Cobbler	[2] (+0.6)	−5.5**	−7.6**	−3.9**
Chippewa	−1.4	−8.9**	−4.7**	−5.0**
Earlaine	[2] (+.1)	−7.3**	−7.3**	−4.8**
Warba	−1.6	−6.2**	−5.9**	−4.5**
Irish Cobbler:				
Houma	+1.5	+4.5**	+6.0**	+3.7**
Green Mountain	+1.1	+4.2**	+4.1**	+2.9**
Chippewa:				
Houma	+3.5	+7.9**	+3.1	+4.8**
Green Mountain	+3.1	+7.6**	+1.2	+4.0**
Earlaine:				
Houma	+2.0	+6.3**	+5.7**	+4.6**
Green Mountain	+1.6	+6.0**	+3.8**	+3.8**
Warba:				
Houma	+3.7**	+5.2**	+4.3**	+4.3**
Green Mountain	+3.3	+4.9**	+2.4	+3.5**
Least difference [3]	3.7**	3.7**	3.7**	2.1**

[1] Each mean for a variety within a county represents 4 tubers; the values given are in milligrams per 100 gm. of raw potato.
[2] Values within parentheses are exceptions.
[3] Least difference between mean values required for odds of 99:1 against the chance occurrence of the difference.
**Significant at the 1-percent level.

obtained in 1938 and 1939. This is shown more clearly in table 4 in which the varietal means for all three locations together in each year are given, and their relative positions within the group are indicated. The ascorbic acid content of the varieties Katahdin and Houma was high in all years; that of Chippewa tended to be low; while that of Irish Cobbler, Warba, and Sebago was intermediate. Values obtained for Earlaine and Green Mountain were not consistent for the 3 years. These varieties may be more variable in ascorbic acid content, or since analyses were made earlier in each succeeding year, the observed differences might be related to different rates of loss of ascorbic acid during storage. Of the other varieties grown in one or two counties during 1938 and 1939, consistently low ascorbic acid values were found for Russet Rural potatoes grown in Wayne and Tompkins Counties in 1938, and in Tompkins and Genesee Counties in 1939; high ascorbic acid values were found for the variety Mohawk (U. S. Department of Agriculture Seedling 46000), grown in Suffolk County in both years; no consistent values were found for the variety Pioneer Rural.

TABLE 4.—*Mean of individual determinations for each variety grown in 3 locations in 1 year, and relative position in the group for each year* [1]

Variety	1937 [2]	Relative position	1938 [2]	Relative position	1939 [2]	Relative position
	Mg.		*Mg.*		*Mg.*	
Katahdin	14.3	1	21.3	1	30.9	3
Earlaine	9.5	5	19.0	2	34.4	1
Houma	14.1	2	18.5	3	31.1	2
Green Mountain	13.3	3	16.3	4	21.0	6
Sebago			16.0	[3] 4a	26.6	[3] 4a
Warba	9.8	[3] 4a	15.5	[3] 4b		
Irish Cobbler	10.4	4	15.2	5	30.7	4
Chippewa	9.3	6	13.1	6	24.9	5

[1] For years 1938 and 1939 each mean represents 24 potatoes, i. e., 8 tubers from each of 3 locations; for 1937 each mean represents 12 potatoes. The values given are in milligrams per 100 gm. of raw potato.
[2] Dates of analyses: 1937, Dec. 17 to Jan. 6; 1938, Oct. 5 to Nov. 29; 1939, Sept. 11 to Nov. 7.
[3] Since these varieties were grown for 2 years only, their relative positions are shown by a letter following a number.

No attempt was made to study the effect of leaving early and midseason varieties in the ground until the late varieties matured. It may be noted by inspection, however, that there was no apparent relation between the ascorbic acid content of a given variety and the season at which it matures. Among the late maturing varieties tested, ascorbic acid values for Katahdin were high, for Russet Rural, low, and for Sebago, intermediate. Among the midseason varieties tested, Houma had high and Chippewa, low, ascorbic acid values.

The varieties Irish Cobbler, Katahdin, Green Mountain, and Chippewa were among those tested by Esselen, Lyons, and Fellers (*3*). Of the five varieties grown in New York State which they tested, the ascorbic acid content of Katahdin potatoes was highest, 15.5 mg. per 100 gm., and that of Chippewa was lowest, 9.9 mg. per 100 gm. They found the mean ascorbic acid content of these varieties from several sources to be as follows: Irish Cobbler 13.1, Katahdin 12.5, Green Mountain 11.7, and Chippewa 9.7 mg. per 100 gm. These differences were not so striking as those found in the present experiment, in which the variety having the highest mean ascorbic acid value in a given year contained over 50 percent more than the variety having the lowest ascorbic acid value. Note that in 1939, when the tubers were analyzed soon after harvest, the mean values for all locations ranged from 21 to 34 mg. per 100 gm. for the several varieties. The mean value for all varieties and all locations for 1939 was approximately 29 mg. of ascorbic acid per 100 gm. If this value is taken as representative of potatoes at harvest, the ascorbic acid value of cooked potatoes soon after harvest would compare favorably with that of tomatoes, even if as much as 25 percent were lost in cooking.

In Tompkins County in 1939, three varieties had mean ascorbic acid values between 40 and 45 mg. per 100 gm. of raw potato. Many individual tubers had values between 40 and 50 mg., with one high value of 54 mg. per 100 gm. These values are comparable to the vitamin C content of citrus fruits.

EFFECT OF LOCATION ON THE ASCORBIC ACID CONTENT OF RAW POTATOES

The differences in the means of ascorbic acid content of potatoes grown in the several locations are shown in table 5. All differences were significant at the 1-percent level. The soils differed in the different locations, however, and in each location the usual amount of

fertilizer for the particular soil type was used. Hence differences in ascorbic acid content of potatoes grown in the several locations may have been due to soil type, fertilizer, or other local environmental conditions. Further studies are needed to determine which factors are involved.

EFFECT OF SOIL REACTION ON ASCORBIC ACID CONTENT OF RAW POTATOES

The potatoes used in this part of the study were grown in a long-time series of soil-reaction plots. The details of the experimental design and treatment of these plots have been published by Smith (*19*, *20*).

Smooth Rural potatoes were grown in Tompkins County on soils of low, medium, and high reaction, with a pH of approximately 4.8, 6.8, and 8.0 or 8.1 in 1937 and 1938. The tubers were stored at 40° and 50° F. in 1937, and at 32°, 40°, and 50° in 1938. Since storage was one of the chief factors under investigation in 1937, four tubers from each lot were analyzed in October and November 1937, and in January, March, and May 1938.

The greatest differences in mean values for ascorbic acid in potatoes stored at different temperatures occurred in January; therefore, eight tubers from each lot grown in 1938 were analyzed in January 1939. The mean values for ascorbic acid content of these potatoes grown on soils of different reaction and stored at different temperatures are shown in tables 6 and 7.

TABLE 5.—*Differences between means of ascorbic acid values of potatoes grown in several locations* [1]

Comparison of locations (counties)	Separate analysis for each year			Analysis for 2 years together	
	[2] 1937	[3] 1938	[4] 1939	[4] 1938	[4] 1939
	Mg.	*Mg.*	*Mg.*	*Mg.*	*Mg.*
Tompkins:					
Suffolk	−1.8**	−10.4**	−8.6**	−10.5**	−8.6**
Wayne	−4.0**	− 6.8**			
Genesee			−4.6**		
Suffolk:					
Wayne	−2.2**	+3.6**			
Genesee			+4.0**		
Least difference [5]	1.4**	1.9**	3.1**	2.5**	2.5**

[1] Values given are in milligrams per 100 gm. of raw potato.
[2] Mean values for 28 potatoes were used in computing these differences.
[3] Mean values for 64 potatoes were used in computing these differences.
[4] Mean values for 56 potatoes were used in computing these differences.
[5] Least difference between mean values for odds of 99:1 against chance occurrence of the difference.
**Significant at the 1-percent level.

Differences between the means of ascorbic acid values of potatoes grown on soils of different reactions are shown in tables 8 and 9. The differences were not consistently in the same direction, and differences showing mathematical significance at the 1-percent level were found in two cases only, between tubers grown on soils of pH 6.8 and 8.1 and stored at 50° F. in March, for the 1937 crop, and between tubers grown on soils of pH 4.8 and 6.8 and stored at 40° in January, for the 1938 crop. These experiments afford no indication of an effect of soil reaction on the vitamin C content of potato tubers.

TABLE 6.—*Mean ascorbic acid values for Smooth Rural potatoes grown in 1937 on soils of different reaction and stored at 40° and 50° F.*[1]

Time of analysis and storage temperature (°F.),	Mean ascorbic acid value for potatoes grown on soil having a reaction (pH) of—			Average on all soils
	4.8	6.8	8.1	
October:	*Mg.*	*Mg.*	*Mg.*	*Mg.*
Before storage	25.4	25.9	27.3	26.2
November:				
40	14.6	13.3	13.9	13.9
50	14.0	14.0	13.0	13.7
Average	14.3	13.7	13.5	13.8
January:				
40	9.5	8.7	7.4	8.5
50	12.1	11.6	13.1	12.3
Average	10.8	10.2	10.2	10.4
March:				
40	9.0	8.3	8.1	8.5
50	10.3	9.5	11.4	10.4
Average	9.7	8.9	9.8	9.4
May:				
40	7.6	7.8	7.6	7.7
50	8.6	7.9	8.2	8.2
Average	8.1	7.8	7.9	7.9

[1] Each mean for 1 soil reaction represents 4 potatoes; means for all reactions represent 12 potatoes. The values given are in milligrams per 100 gm. of raw potato.

TABLE 7.—*Mean ascorbic acid values for Smooth Rural potatoes grown in 1938 on soils of different reaction and stored at 32°, 40° and 50° F.*[1]

Storage temperature (°F.)	Mean ascorbic acid value for potatoes grown on soil having a reaction (pH) of—			Average on all soils
	4.8	6.8	8.0	
	Mg.	*Mg.*	*Mg.*	*Mg.*
32	8.1	[2] 9.9	7.7	8.5
40	11.5	8.7	9.3	9.8
50	15.0	14.5	13.9	14.5
Average	11.5	11.0	10.3	

[1] Each mean represents 8 potatoes. The values given are in milligrams per 100 gm. of raw potato. Analysis made in January 1939.
[2] Represents only 7 potatoes.

EFFECT OF STORAGE TEMPERATURE ON ASCORBIC ACID CONTENT OF RAW POTATOES

Smooth Rural potatoes lost approximately one-half of their original vitamin C content after a month of storage at 50° F. (table 10). The loss continued throughout the 7-month storage period at a decreased rate, until by the end of the period a total of 70 percent had been lost. Similar results were obtained at a storage temperature of 40°, except that the loss had reached approximately 70 percent by the end of the third month.

The differences between means of ascorbic acid values for potatoes stored at 40° and for those stored at 50° F. are shown in tables 11 and 12. Differences significant at the 1-percent level were found when tubers grown at all soil reactions and stored at 40° and 50° were com-

pared in January and March, for the 1937 crop, and in January, for the 1938 crop. Differences between values for tubers stored at 32° and 50° (table 12) were also significant. These studies indicate that losses of vitamin C when potatoes are stored at 50° tend to be less than losses when potatoes are stored at 40°. Rolf (*12*) found that the vitamin C losses were less for potatoes stored at 15.5° C. (59° F.) than for those stored at 4.5° C. (40° F.).

TABLE 8.—*Differences between mean ascorbic acid values for Smooth Rural potatoes grown on soils of different reaction in 1937* [1]

Comparison according to soil pH	Time of analysis and storage temperature (° F.)												
	October, before storage	November			January			March			May		
		40	50	Average	40	50	Average	40	50	Average	50	50	Average
	Mg.	*Mg.*	*Mg.*	*Mg.*	*Mg.*	*Mg.*	*Mg.*	*Mg.*	*Mg.*	*Mg.*	*Mg.*	*Mg.*	*Mg.*
4.82:													
6.8	+0.5	−1.3	0.0	−0.6	−0.8	−0.5	−0.6	−0.7	−0.8	−0.8	+0.2	−0.7	−0.3
8.1	+1.9	−.7	−1.0	−.8	−2.1	+1.0	−.6	−.9	+1.1	+.1	0	−.4	−.2
6.8:													
8.1	+1.4	+.6	−1.0	−.2	−1.3	+1.5	0	−.2	+1.9**	+.9	−.2	+.3	+.1
Least difference [2]	3.1**				2.8**	2.8**		1.7**	1.7**	1.2**	1.6**	1.6**	

[1] Values given are in milligrams per 100 gm. of raw potato.
[2] Least difference between mean values for odds of 99:1 against chance occurrence of the difference.
**Significant at the 1-percent level.

TABLE 9.—*Differences between mean ascorbic acid values for Smooth Rural potatoes grown on soils of different reaction in 1938* [1]

Comparison according to soil pH	Storage temperature (°F.)			Average
	32	40	50	
	Mg.	*Mg.*	*Mg.*	*Mg.*
4.8:				
6.8	+1.8	−2.8**	−0.5	−0.5
8.0	−0.4	−2.2	−1.1	−1.2
6.8:				
8.0	−2.2	+0.6	−.6	−.7
Least difference [2]	2.6**	2.6**	2.6**	1.5**

[1] Each figure represents 8 potatoes. Values given are in milligrams per 100 gm. of raw potato; analyses made in January 1939.
[2] Least difference between mean values for odds of 99:1 against chance occurrence of the difference.
** Significant at the 1-percent level.

TABLE 10.—*Effect of storage and cooking on mean values for ascorbic acid content of Smooth Rural potatoes* [1]

Time of analysis	Ascorbic acid content at indicated storage temperature (°F.) of—					
	Raw potatoes [2]		Boiled potatoes [3]		Cooking Water [3]	
	40	50	40	50	40	50
	Mg.	*Mg.*	*Mg.*	*Mg.*	*Mg.*	*Mg.*
October (before storage)	26.2	26.2	16.1	16.1	3.1	3.1
November	14.0	13.7	9.8	10.7	2.4	1.2
January	8.5	12.3	5.8	8.0	1.4	2.6
March	8.5	10.4	5.9	7.4	1.3	1.0
May	7.7	8.2	5.3	5.1	.7	.4

[1] Values given are in milligrams per 100 gm. of raw potato.
[2] Each figure represents 12 potatoes.
[3] Each figure represents 3 lots of cooked potatoes.

TABLE 11.—*Differences between means of ascorbic acid values of Smooth Rural potatoes grown in 1937 and stored at 40° and 50° F.*[1]

Time of analysis	Storage temperatures (° F.) compared	Soil reaction (pH)			
		4.8	6.8	8.1	Average
		Mg.	*Mg.*	*Mg.*	*Mg.*
November	40:				
	50	−0.6	+0.7	−0.9	−0.3
January	40:				
	50	+2.6	+2.9**	+5.7**	+3.8**
	Least difference [2]	2.8**	2.8**	2.8**	1.6**
March	40:				
	50	+1.3	+1.2	+3.3**	+1.9**
	Least difference [2]	1.7**	1.7**	1.7**	1.0**
May	40:				
	50	+1.0	+ .1	+ .6	+ .5
	Least difference [2]	1.6**	1.6**	1.6**	.9**

[1] Means for each soil reaction, storage time, and temperature represent 4 tubers. Values given are in milligrams per 100 gm. of raw potato.
[2] Least difference between mean values for odds of 99:1 against chance occurrence of the difference.
**Significant at the 1-percent level.

TABLE 12.—*Differences between means of ascorbic acid values for Smooth Rural potatoes grown in 1938 and stored at different temperatures* [1]

Storage temperatures (° F.) compared	Soil reaction (pH)			
	4.8 [2]	6.8 [2]	8.0 [2]	Average [3]
	Mg.	*Mg.*	*Mg.*	*Mg.*
32:				
40	+3.4**	−1.2	+1.6	+1.3
50	+6.9**	+4.6**	+6.2**	+6.0**
40:				
50	+3.5**	+5.8**	+4.6**	+4.7**
Least difference [4]	2.6**	2.6**	2.6**	1.5**

[1] Analyzed in January 1939. Values given are in milligrams per 100 gm. of raw potato.
[2] Each figure represents 8 potatoes.
[3] Each figure represents 24 potatoes.
[4] Least difference between mean values for odds of 99:1 against chance occurrence of the difference.
**Significant at the 1-percent level.

EFFECT OF FERTILIZER TREATMENT ON THE ASCORBIC ACID CONTENT OF RAW POTATOES

VARIATIONS IN FERTILIZER ANALYSIS

Fertilizer containing nitrogen, phosphorus, and potassium in the ratio of 1–2–3 was varied by leaving out part or all of each of the three elements, one at a time. The equivalent of 2,000 pounds per acre of each of the fertilizers was added to the soil on which potatoes were grown. The potatoes used for the experiment were grown in Oswego County on muck soil. The variety Chippewa was used in 1938, and Green Mountain, in 1939. The average values obtained for the 2 years are shown in table 13; the difference between these values and the least difference neecssary to show mathematical significance at the 1-percent level appear in table 14.

TABLE 13.—*Effect of fertilizers of different composition on the ascorbic acid content of potatoes* [1]

Year	Analysis of fertilizer (N–K–P)						
	4–8–12	0–8–12	4–0–12	4–8–0	2–8–12	4–4–12	4–8–8
	Mg.	*Mg.*	*Mg.*	*Mg.*	*Mg.*	*Mg.*	*Mg.*
1938 [2]	9.2	6.5	9.3	7.4	9.9	9.4	7.9
1939 [2]	13.3	12.6	12.0	14.3	12.0	13.4	13.6
Average [3]	11.4	9.6	10.7	10.9	10.7	11.6	10.7

[1] Values given are in milligrams per 100 gm. of raw potato.
[2] Each figure represents 8 potatoes.
[3] Each figure represents 16 potatoes.

TABLE 14.—*Differences between means of ascorbic acid values of potatoes treated with fertilizers having different analyses for N, P, and K* [1]

Variant	Analyses compared	Each year analyzed separately		Two years analyzed together [3]
		1938 [2]	1939 [2]	
		Mg.	*Mg.*	*Mg.*
N	4–8–12 and 2–8–12	+0.7	−1.3	−0.7
	2–8–12 and 0–8–12	−3.4**	+.6	−1.1
	4–8–12 and 0–8–12	−2.7**	−.7	−1.8**
P	4–8–12 and 4–4–12	+.2	+.1	+.2
	4–4–12 and 4–0–12	−.1	−1.4	−.9
	4–8–12 and 4–0–12	+.1	−1.3	−.6
K	4–8–12 and 4–8–8	−1.3	+.3	−.7
	4–8–8 and 4–8–0	−.5	+.7	+.2
	4–8–12 and 4–8–0	−1.8	+1.0	−.5
Least difference, 1 year [4]		2.4**	1.9**	
Least difference, 2 years [4]		2.3**	2.3**	1.6**

[1] Values given are in milligrams per 100 gm. of raw potato.
[2] Mean values for 8 potatoes were used in computing these differences.
[3] Mean values for 16 potatoes were used in computing these differences.
[4] Least difference between mean values for odds of 99:1 against chance occurrence of the difference.
**Significant at the 1-percent level.

None of the variations in phosphorus or potassium produced differences which were significant at the 1-percent level. Omission of nitrogen from the fertilizer was accompanied by a mathematically significant decrease in the ascorbic acid content of the potatoes grown in 1938, but not in the content of those grown in 1939. Possibly the nitrogen applied in 1939 was less available than that applied in 1938 because of the difference in rainfall in the two seasons. The United States Weather Bureau station in the city of Oswego recorded for 1938 15.39 inches of rainfall from May through September and 8.10 inches for June, July, and August, as compared with 8.07 inches from May through September and 4.67 inches for June, July, and August, 1939. No records of rainfall were made at the farm where the potatoes were grown.

MINOR ELEMENTS

Smooth Rural potatoes, grown in Steuben County on gravelly silt loam having 1,000 pounds per acre of 5–10–5 fertilizer, were treated as follows: To one lot no additions were made; to a second lot were added six minor elements, copper, zinc, boron, manganese, magnesium, and iron; to a third lot was added 12 tons per acre of barnyard manure. Eight potatoes of each lot were tested for ascorbic acid content.

The average ascorbic acid values were 11.3, 12.4, and 11.5 mg. per 100 gm. for the three lots. None of the differences are mathematically significant, even at the 5-percent level. In both this study and that of Lyons and Fellers (7), boron, zinc, manganese, and magnesium were used; but this series also included copper and iron, whereas that of Lyons and Fellers included lead, mercury, and cobalt. The ascorbic acid content of potatoes grown on soils to which a complete fertilizer was added was not affected in either case.

EFFECT OF BOILING ON ASCORBIC ACID CONTENT OF POTATOES

The results of the cooking tests made on stored potatoes in the season of 1937–38 are shown in table 10. On an average, approximately two-thirds of the vitamin C value of the raw tuber remained in the boiled potato, and an additional amount was found in the cooking water. Actual destruction of ascorbic acid varied considerably, but was under 20 percent in 18 of 27 cooking tests.

SUMMARY

Varietal differences were observed in the ascorbic acid content of potatoes grown in different localities in New York State in three seasons. High values were obtained for the varieties Katahdin and Houma in all 3 years; the values for Chippewa tended to be low; while those for Irish Cobbler, Warba, and Sebago were intermediate. Less consistent results were obtained for Earlaine and Green Mountain.

The ascorbic acid content of potatoes grown in different locations showed marked variation. Whether this was due to fertilizer, soil type, climate, or other conditions is not known.

Under the conditions of these experiments neither soil reaction, the amount of nitrogen, phosphorus, and potassium in the fertilizer, nor the addition of minor elements to soil to which a complete fertilizer had been added had a consistent influence on the ascorbic acid content of potatoes.

Losses of ascorbic acid tended to occur more slowly in potatoes which were stored at 50° F. than in those stored at 40°.

Under the conditions of these experiments approximately two-thirds of the ascorbic acid content of the raw tuber remained in the boiled potato.

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SELF-INCOMPATIBILITY IN SEVERAL SPECIES OF RIBES IN THE WESTERN STATES [2]

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INTRODUCTION

The quantity and viability of seeds produced by *Ribes* [5] in the white pine areas of the western part of the United States are important factors in the control of the destructive blister rust disease of white pines (*Pinus* spp.) caused by the fungus *Cronartium ribicola* Fischer. Primary control is accomplished by suppressing the populations of *Ribes* within stands of white pine to the point where they cannot cause significant damage (*2*). Thereafter the factors affecting regeneration of the species from this residuum are of special interest because of their bearing upon the planning of long-range control.

Plant competition, shade, drought, winter-kill, physical injury, fungi, and insects are recognized as the principal factors unfavorable to the regeneration of *Ribes*. Reestablishment of *Ribes* in white pine forests can be discouraged by proper forest management based on correct interpretation of the ecology of pine and *Ribes* (*1*). Of the many factors involved in the reestablishment of *Ribes* in a control area this paper is primarily concerned with one, seed production.

The flowers of *Ribes* are perfect and homomorphic. Under natural conditions in forested areas fruiting is generally heaviest when the plants are gregarious, that is, when an abundance of pollen is close at hand. Insects are the chief carriers of *Ribes* pollen, though wind and water likewise disseminate it. The annual output of *Ribes* seeds depends on the weather at the time of flowering, the activity of insect pollinators, and the consumption of fruit and seeds by rodents. *Ribes* fruits are highly favored by mice, chipmunks, and ground squirrels, which eat and destroy the seeds. One caged chipmunk,[6] overnight, ate and destroyed about 6,000 seeds of *R. viscosissimum* Pursh. Birds scatter *Ribes* seeds but apparently do not necessarily destroy

[1] Received for publication December 4, 1942. Greenhouse and laboratory facilities used by the Bureau of Entomology and Plant Quarantine at the University of California at Berkeley are maintained in cooperation with the College of Agriculture through its Department of Forestry.

[2] "Incompatibility" as used in this paper has the significance assigned by Stout (*9*) [3] and implies that self- and cross-incompatibility are present and interrelated.

[3] Italic numbers in parentheses refer to Literature Cited, p. 71.

[4] The authors wish to acknowledge the helpful suggestions made by E. B. Babcock, Carl Epling, and T. H. Goodspeed, of the University of California, who reviewed this manuscript.

[5] The generic name *Ribes* is used in this paper to indicate both currants and gooseberries.

[6] ROCKIE, W. A. STUDIES IN RIBES ECOLOGY, IDAHO. *In* Office of Blister Rust Control (U. S. Bur. Plant Indus.) report, Blister Rust Work in the Far West, January 1 to December 31, 1928, pp. 26–75, 1929. [Unpublished interoffice report on file in Div. of Plant Disease Control, U. S. Bur. of Ent. and Plant Quar., Washington, D. C.]

their viability. C. R. Quick collected droppings from robins and chickadees and subsequently obtained 60 to 90 percent germination of recovered seeds of *R. cereum* Dougl. and *R. nevadense* Kell. The bird droppings probably included both regurgitated and fecal material.

PREVIOUS WORK

Little work seems to have been done on controlled pollination of the native wild *Ribes* of the United States. A posthumous publication by East (*4, p. 472*) stated that "In the Saxifragaceae * * * there is much homogamy, though there are certain highly protandrous and protogynous species," and that many tested species of *Deutzia, Hydrangea, Philadelphus,* and *Ribes* appeared to be self-fertile. However, according to Karl Sax,[7] who prepared East's paper for publication, this statement was probably based on general information and observation and not upon specific data; it may have referred to varieties of cultivated currants and gooseberries. Janczewski (*6, p. 220*), although not commenting specifically on compatibility in *Ribes,* made the following statement which may indicate that he believed the plants to be sometimes self-fertile:

> The flowers of *Ribes* are frequently visited and pollinated by insects. The homogamous flowers may well be passed by, for their pollen easily falls on the stigmata ready to receive it. [Translated from the French.]

To obtain further information on fruit production in *Ribes,* experiments were undertaken to answer the question, Do certain *Ribes,* native to the white pine areas of the Western States, produce viable seed equally well by cross-pollination and self-pollination, or is one type of pollination chiefly responsible for setting the fruits?

METHODS AND MATERIALS

POLLINATION

In March 1940 hand-pollination of *Ribes* flowers (within species) was undertaken on *R. glutinosum* Benth., *R. roezlii* Regel, and *R. gracillimum* Cov. and Britt., which had been transplanted to the Botanical Garden of the University of California at Berkeley.[8] In May of the same year the work was extended to *R. roezlii* and *R. nevadense* growing naturally in the Sierra Nevada of California, and to *R. viscosissimum* and *R. lacustre* (Pers.) Poir. in northern Idaho. In May 1941 tests were repeated on *R. roezlii* in the Sierra Nevada. The period of flowering for *Ribes* is short, usually not more than a month under favorable conditions. For *R. roezlii,* in particular, the schedules for controlled pollination were such that any cyclic changes in compatibility should have been reflected in the results.

All pollination work was carried out by the usual emasculation and bagging procedure. Half-pound kraft bags were used to exclude unwanted pollen from flowers and inflorescences. Implements were kept sterile by frequent immersion in ethyl alcohol. The technique employed is believed to have met fully the requirements that (1) the pollen should be good, (2) the stigma should be receptive, and (3) the stigma should receive an adequate supply of pollen.

[7] Correspondence.

[8] In cooperation with the Botanical Garden, directed by T. H. Goodspeed, the Bureau of Entomology and Plant Quarantine maintains a collection of about 80 species of *Ribes.*

Since flowers of the currants are relatively small, an inflorescence rather than a single flower was taken as the working unit. Thus the several flowers of a raceme were usually emasculated and enclosed within the same protective bag. For convenience the gooseberries were handled in a similar manner, although they had only one to three flowers per raceme, and several closely approximate flowers were often enclosed in one bag.

Since the *Ribes* flowers involved in these tests, especially *R. roezlii*, tended to be protogynous, care was taken to select flower buds from which the pistil did not protrude. The protogynous character of these flowers suggests that cross-pollination would be favored under natural conditions.

In many cases reciprocal crosses were made; that is, pollen from previously bagged selfs on one bush was used on the bagged crosses of a second bush, and pollen from selfs on the second bush was used on crosses of the first bush. In the remaining cases pollen for crosses came from plants not otherwise involved. All pollen from unbagged flowers used in the experiments was taken from unopened buds and from plants reasonably remote from those on which it was used. The chance that pollen from clones was involved is therefore small.

The selfs were pollinated by anthers from within the same protective bag. After being bagged, both the selfs and the crosses were pollinated two or three times at intervals of 2 to 4 days. With a few exceptions each bush involved in the experiment carried an equal number of bags for self-pollination and cross-pollination.

SEED GERMINATION

Ripe fruits were collected during the course of field and garden tests to permit a comparison of the viability of seed from natural and controlled sources.

The open-pollinated seeds of *Ribes glutinosum* and *R. nevadense*, and of *R. roezlii* from the Sierra Nevada, were collected from the same bushes on which the pollination work was done; those of *R. viscosissimum* from northern Idaho and of *R. roezlii* from the University of California Botanical Garden were taken from other bushes in the same locality.

The seeds that matured from the several controlled-pollination tests and those obtained from natural pollination were extracted (*7*) from the fruits during the fall of 1940 and on December 3 were planted in autoclaved river sand wet with Hoagland's (*5*) mineral nutrient solution. The seeds of each species were planted in flats of wet sand, treated with copper oxalate at the rate of 6 gm. per square foot of culture surface to control damping-off (*8*), and then stratified for a period of time and at a temperature that previous experience had shown was most satisfactory.

The first, or primary, stratification treatments were as follows: *Ribes glutinosum*, at 2.2° C. for 20 weeks; *R. nevadense*, at 0° for 24 weeks; *R. roezlii*, at 2.2° for 18 weeks; and *R. viscosissimum*, at 0° for 24 weeks. The second, or retrial, stratification treatments for all the species were generally at 0° for 20 weeks. Germination periods in the greenhouse were of 5 weeks' duration.

RESULTS OF TESTS

The tests on *Ribes gracillimum* were unsuccessful because of a serious twig blight, which damaged the plants and prevented setting of fruits by either cross- or self-pollination. The protective bags on *R. lacustre* were disturbed by some person or animal; therefore, the tests could not be considered as valid. In the other species ripe fruits were obtained in varying amounts from cross-pollination, but no fruits were formed as a result of self-pollination. Table 1 reports the results of the pollination tests.

No difficulties were experienced in the germination tests on the collected seeds. As shown in table 2, viable seed was produced by the controlled cross-pollination work.

TABLE 1.—*Comparison of number of fruits and seeds from controlled cross- and self-pollination of several* Ribes *species native to the Western States*

Ribes species	Location of test plants	Cross-pollination tests					Self-pollination tests		
		Inflorescences	Flowers	Fruits set	Matured fruits	Seeds	Inflorescences	Flowers	Matured fruits
		No.	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*
R. roezlii	University of California Botanical Garden, Berkeley.	8	[1] 32	11	10	496	7	[1] 28	0
	Sierra National Forest, Chowchilla Mountain.	25	144	65	[2] 35	1,737	25	160	0
	Stanislaus National Forest, Cow Creek.	51	217	116	[2] 56	(3)	49	258	0
R. glutinosum	University of California Botanical Garden, Berkeley.	12	84	34	30	1,010	12	[1] 72	0
R. nevadense	Sierra National Forest, Chowchilla Mountain.	16	80	39	32	725	16	83	0
R. viscosissimum	Clearwater Timber Protective Association, Idaho, Deer Creek and Powder House.	14	64	21	13	376	30	135	0
Total		126	621	286	176	4,344	139	736	0

[1] Number of flowers estimated from average number per bag proposed for the tests.
[2] Some additional fruits were destroyed by rodents.
[3] Seeds were not extracted.

TABLE 2.—*Comparison of data for germination tests on* Ribes *seeds from controlled cross- and open-pollinated flowers, 1940*

Ribes species	Location of test plants	Cross-pollinated seeds				Open-pollinated seeds			
		Cultures	Seeds	Seedlings	Germination	Cultures	Seeds	Seedlings	Germination
		No.	*No.*	*No.*	*Percent*	*No.*	*No.*	*No.*	*Percent*
R. roezlii	University of California Botanical Garden, Berkeley.	6	496	444	89.5	5	[1] 500	451	90.2
	Sierra National Forest	20	1,435	817	56.9	5	452	408	90.3
R. glutinosum	University of California Botanical Garden, Berkeley.	15	939	876	93.3	9	900	798	88.7
R. nevadense	Sierra National Forest	15	724	567	78.3	4	400	299	74.8
R. viscosissimum	Clearwater Timber Protective Association, Idaho.	8	376	284	75.5	3	[1] 300	187	62.3
Total or average.		64	3,970	2,988	75.3	26	2,552	2,143	84.0

[1] Seeds from same locality as cross-pollinated seeds, but not from same bushes.

DISCUSSION

Self-incompatibility in *Ribes roezlii*, *R. glutinosum*, *R. nevadense*, and *R. viscosissimum* is clearly shown by the data in table 1. From the 736 *Ribes* flowers that were self-pollinated, not a single mature fruit was obtained. On the other hand, cross-pollination of 621 flowers resulted in the setting of 286 fruits. From cross-pollination 176 mature fruits were ultimately obtained for seed-germination tests. More would have been obtained had not rodents destroyed a number of the experimental fruits about the time they were getting ripe. Other fruits were lost through natural dropping before they had matured.

Under natural conditions many *Ribes* flowers fail to produce fruits. The following records are a quantitative measure of this statement and show that the 46 percent of fruit set from controlled pollination is about what we might expect from a natural fruit crop.

At Cow Creek, Stanislaus National Forest, a study of fruiting habits was made on a series of *Ribes roezlii* bushes growing on a 1936 burn in mature timber and fruiting for the first time in 1941. Practically all the bushes originated in 1937, the year after the fire. On May 21, 1941, 37 bushes were bearing 974 flowers. Many more bushes of the same age did not flower or fruit in 1941. As the season progressed, the total number of fruits in various stages of maturity remaining on the 37 bushes were as follows: 376 on June 3, 109 on June 18, 42 on July 11, and 25 on August 13. The average stage of development of the 376 fruits present on June 3 was approximately the same as that of the 192 *R. roezlii* fruits set under controlled cross-pollination as reported in table 1. In another study in the spring of 1937, a favorable year for flower and fruit production, it was found that on 26 vigorous 5- to 6-year-old *R. viscosissimum* bushes occurring naturally in Upper Basin, St. Joe National Forest, Idaho, 427 racemes developed 3,847 flowers, which in turn produced 1,752 mature fruits. In the instances cited, 39 percent of the *R. roezlii* flowers and 45 percent of the *R. viscosissimum* flowers produced fruits under natural conditions.

East (3) and others have shown that when self-incompatibility is conditioned by a series of multiple allelomorphs the existence of cross-incompatible plants in the same population is a necessary corollary. The fact that in controlled crosses, as well as under natural conditions, less than 50 percent of the flowers set fruits agrees with the assumption that some degree of cross-incompatibility also exists in the *Ribes* species tested.

The reaction of *Ribes nevadense* to self-pollination was quite different from that of the other *Ribes* species. Of the 83 test flowers of *R. nevadense* 15 formed abortive fruits, whereas only 1 abortive fruit was set by each of the species *R. roezlii* and *R. viscosissimum*, and none by *R. glutinosum*.

Rodents took a heavy toll of *Ribes roezlii* fruits, but since the loss did not occur until fruits were well formed and nearly mature, it was not involved in the results shown in table 1 for the self-pollination tests.

Data in table 2 show that controlled cross-pollination as practiced in the tests of 1940 resulted in the formation of viable seed, and that, with one exception, the viability of the experimentally produced seed

compared favorably with that of seed resulting from open pollination. In the tests on *Ribes roezlii* from the Sierra National Forest, low viability was encountered in cross-pollinated seeds taken from 2 bushes, and average germination of only 2 percent was obtained in 6 of the 20 cultures. The remaining 14 cultures averaged 82 percent germination, which is comparable to that of the open-pollinated sample. In view of the variations that are possible in the results of greenhouse germination tests, and insofar as the interest of this report is concerned, no significance is attached to these differences. Observations and experimental data of the past 10 years have shown that the physical and physiological characteristics of *Ribes* seed vary considerably. With these limitations in mind it can be stated that the controlled pollination produced seeds that were normal in respect to average number per fruit, and in respect to size, color, weight, and germination.

It cannot be concluded from these tests that isolated bushes of *Ribes roezlii*, *R. nevadense*, *R. viscosissimum*, and *R. glutinosum* will never produce mature fruits under natural conditions, because little evidence is available on the distance of flight and the habits of insects in searching for and pollinating *Ribes* flowers, and because some degree of self-compatibility may be possible. The chances of fruit production, however, would appear to become progressively poorer as the number of *Ribes* bushes per acre is reduced by eradication work and by natural suppression. Furthermore, since rodents have a strong liking for fruits and seeds of *Ribes*, their consumption of fruit becomes more important when viewed in the light of a diminishing crop. These factors should aid the natural suppression of *Ribes* which normally takes place in ecologically maturing forest stands, and they should mean that the efforts of artificial suppression will be expedited by natural phenomena once the number of flowering *Ribes* per acre has been substantially reduced.

SUMMARY

In the spring of 1940 controlled pollination of 4 species of *Ribes* native to the Western States was undertaken. These tests were made in the Botanical Garden of the University of California at Berkeley on transplanted *R. roezlii* and *R. glutinosum*, in the Sierra Nevada of California on naturally occurring *R. roezlii* and *R. nevadense*, and in northern Idaho on naturally occurring *R. viscosissimum*. Tests were repeated in 1941 on *R. roezlii* occurring in the Sierra Nevada. Cross-pollination was successful for all the species tested, and produced 176 mature fruits from 621 flowers that were pollinated. Self-pollination of the same species under similar conditions failed to produce a single mature fruit. It is concluded, therefore, that under natural conditions the seed-bearing fruits of these 4 species of *Ribes* normally result from cross-pollination.

Viability of seed obtained by controlled cross-pollination in the tests of 1940 compared favorably with that of seed resulting from open pollination occurring naturally on the same plants of the same species, or on plants of the same species in the immediate locality. The average number of seeds per fruit and the percentage of flowers which set fruits were substantially the same for open and controlled pollination.

Self-incompatibility of *Ribes* will prevent heavy fruiting in scattered light populations of these plants. Also, rodent pressure is of increased significance when fruits are scarce. Together, these factors should simplify the control of blister rust disease in the white pine areas of the Far West.

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HUSK DEVELOPMENT OF SWEET CORN AS AFFECTED BY MOISTURE SUPPLY, AN IMPORTANT FACTOR IN CORN EARWORM CONTROL [1]

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INTRODUCTION

The treatment of ears of a given variety of sweet corn (*Zea mays L.*) grown in different fields during different seasons of the year with mineral oil containing insecticides for control of the corn earworm (*Heliothis armigera* (Hbn.)) has been found to vary in effectiveness. Such variation has been noticed even in fields planted from the same lot of seed and grown under conditions that seemed to be similar except as to time of planting. It is known that the effectiveness of this treatment, which is directed against the larvae after they have entered the ears and while they are concentrated in and feeding on the silk lying between the tip of the husk and the tip of the cob, is dependent on characters of the husk, including its extension beyond the tip of the cob. Therefore, it was thought that a comparison of husk measurements made at the time of roasting-ear harvest in fields of the same variety planted on different dates might give some explanation for these differences in control. Measurements were made of a large number of ears of many varieties, but observations on only two varieties are reported in this paper.

OBSERVATIONS ON MARCROSS 6.13

During 1939 three plantings of the variety Marcross 6.13 were observed. The seed, under the name "Whip Marcross," had been obtained from one seedsman. The first of the plantings was a commercial field at Beverly, N. J., and the other two were variety-trial plots, one 2 miles from the commercial planting and the other at New Brunswick, N. J. In each of the first two fields 100 ears were examined on July 6; in the third field 43 ears were examined on July 15.

The results of husk measurements of these ears are summarized in table 1. It was found that the husks in the two fields at Beverly were similar in length but that the husks in the New Brunswick field were much shorter. If the average husk length of ears in the fields near Beverly is considered as having a value of 100, this value for the field at New Brunswick is 44. The factor causing this difference seemed to be one of moisture, since the fields at Beverly were grown during a period of approximately normal precipitation whereas the New Brunswick field was subjected to a severe drought.

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TABLE 1.—*Extension of the husks beyond the cob tips of ears of Marcross 6.13 sweet corn in 3 fields at time of roasting-ear harvest in New Jersey, 1939*

Extension of husk beyond the cob (inches)	Ears falling in stated classes of husk extension		
	Commercial field at Beverly	Variety-trial plot at Beverly	Variety-trial plot at New Brunswick
	Percent	*Percent*	*Percent*
3.1 to 3.5		1.0	
2.6 to 3.0	7.0	4.0	
2.1 to 2.5	18.0	19.0	2.3
1.6 to 2.0	29.0	31.0	9.3
1.1 to 1.5	24.0	26.0	20.9
0.6 to 1.0	15.0	15.0	18.6
0.1 to 0.5	5.0	3.0	23.3
0	2.0	1.0	25.6
	Length of husk extension		
	Inches	*Inches*	*Inches*
Longest	2.9	3.4	2.1
Shortest	0	0	0
Average	1.6±0.07	1.6±0.06	0.7±0.09

OBSERVATIONS ON GOLDEN CROSS BANTAM

In 1940 similar observations were made on the variety Golden Cross Bantam near Jobstown, N. J. Six fields were observed all of which had been planted from one lot of seed. Fields 1 to 4, each of about 5 acres, were planted on different dates in equal quarters of one large field, whereas fields 5 and 6, each of about 15 acres, were several miles away although similar in soil type and fertility. The results of husk measurements of ears in these fields are given in table 2.

TABLE 2.—*Extension of the husks beyond the cob tips of ears of Golden Cross Bantam sweet corn in 6 fields at time of roasting-ear harvest, Jobstown, N. J., 1940*

Extension of the husk (inches)	Ears falling in stated classes of husk extension					
	Field 1	Field 2	Field 3	Field 4	Field 5	Field 6
Longer than cob:	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
6.1 to 6.5				0.16		
5.6 to 6.0				.16		
5.1 to 5.5				.62	0.24	0.44
4.6 to 5.0		0.40		1.39	.48	1.11
4.1 to 4.5		1.20	1.40	3.42	3.01	5.56
3.6 to 4.0		4.82	4.81	9.16	7.59	17.56
3.1 to 3.5	0.50	10.04	15.23	21.43	14.46	24.89
2.6 to 3.0		15.86	24.85	25.31	30.60	29.55
2.1 to 2.5	3.00	23.09	23.85	22.05	23.50	15.33
1.6 to 2.0	5.50	17.87	18.84	11.80	12.05	4.67
1.1 to 1.5	10.50	14.06	8.22	3.88	6.02	.67
0.6 to 1.0	14.50	8.64	2.20	.62	1.57	.22
0.1 to 0.5	7.50	.40	.20		.12	
Same as cob	37.00	3.62	.40		.36	
Shorter than cob:						
0.1 to 0.5	5.00					
0.6 to 1.0	8.00					
1.1 to 1.5	4.00					
1.6 to 2.0	3.50					
2.1 to 2.5	1.00					
	Length of husk extension					
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Longest	3.1	4.7	4.5	6.3	5.4	5.4
Shortest	−2.2	.0	.0	.8	.0	.6
Average	0.23±.07	2.11±.04	2.44±.03	2.80±.03	2.64±.03	3.08±.03
Planting date	June 3	June 11	June 18	June 27	July 5	July 13–16.
Date examined	Aug 21	Aug. 23–29.	Sept. 7–9	Sept. 12	Sept. 24	Oct. 4.
Number of ears	200	498	499	644	830	450.

Extraordinary differences were observed in the length of husks in these fields. If, as seems to be reasonable from many previous observations, the ears of field 5 were of normal development and the average husk length is considered as having a value of 100, the value for the other fields would be as follows: 9 for field 1, 80 for field 2, 92 for field 3, 106 for field 4, and 117 for field 6. Not only were the husks in field 1 much shorter than usual, but more than one-third of them were not longer than the cobs, and more than one-fifth were shorter than the cobs, a condition that is rare in this variety. Ears of this variety showing husks of different lengths with respect to the cob are illustrated in figure 1.

The records indicated that an adverse factor had affected development of husks in field 1 to an extreme degree, and to a much less degree in field 2. Since the summer of 1940 was deficient in precipitation, it seemed likely that lack of moisture might be a responsible factor. Precipitation in the vicinity of Jobstown during June amounted to 1.57 inches, which was 2.21 inches less than normal, and during July to 1.66 inches, which was 3.04 inches less than normal. Rain became more frequent from August 7 to 25, when 3.46 inches fell, but it did not become abundant until August 26 to September 2, when 8.73 inches fell. Therefore, field 1 and to a less degree field 2 were exposed to severe drought during much of the period of ear development.

DISCUSSION

The evidence seemed to point to lack of moisture as the cause of the unusually short husks observed in the plot of Marcross 6.13 at New Brunswick in 1939 and in field 1 of Golden Cross Bantam in 1940. It is probable, however, that the degree of husk shortening may vary with the length and severity of drought encountered by the growing plant, especially during the period when the ears are developing. Since droughts are usually much less severe than the extreme conditions described, the effect on the husks is usually correspondingly less.

It is well known that corn plants subjected to drought become stunted. If the drought is continuous, the husks are usually affected more than the cobs, which grow over a longer period and are therefore more likely to receive the moisture they need to complete their normal development. In the study here reported it was noted that in field 1 of Golden Cross Bantam the husks had completed their growth under dry conditions and were severely stunted, but the subsequent rainfall caused the cobs to make a normal growth so that their length was disproportionate to that of the husks (fig. 1, B). This seems to show that stunting of the plants of this field was limited to those parts that completed growth under the dry conditions and that the parts that grew subsequently to precipitation were more normal.

The rapidity with which earworms penetrate corn ears depends principally on the length and tightness of the husk. Length of the husk beyond the tip of the cob determines the length of the interior silk strands or the abundance of silk that is available as food for the larvae within the ear. Tightness of the husk determines the degree to which the silk strands are pressed together, and this affects the behavior of larvae after they enter the silk mass. If the husk is loose, they may crawl between the silk strands and reach the kernels

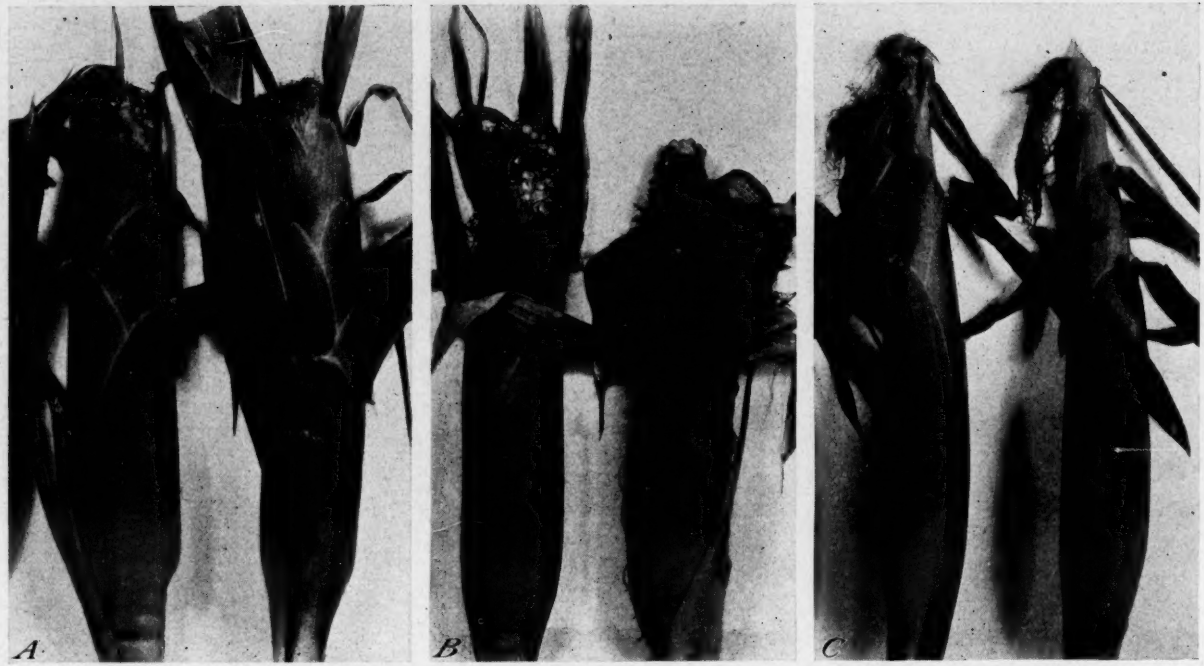

FIGURE 1.—Ears of Golden Cross Bantam sweet corn having (*A*) cobs and husks of equal length, (*B*) cobs longer than the husks, and (*C*) husks 2 to 3 inches longer than the cobs.

soon after hatching, but if the husk is tight the larvae can reach the kernels only by eating a passage through the tightly packed silk. Ears having relatively long, tight husks, in which the larval population is concentrated in the interior silk for several days, can be protected by an insecticidal oil because the entire larval population is reached by it, whereas ears having comparatively short, loose husks, in which many of the larvae are able to disperse to the kernels soon after entering the ears, are not so well protected by the insecticide because it reaches fewer of them. Ears having husks stunted through lack of moisture fall in the latter class, because of the reduced amount and compactness of the silk within the husk tips and the increased limpness and looseness of the husks.

It is thus seen that drought reduces the effectiveness of an insecticidal oil in a variety of sweet corn the husk characters of which under normal conditions are favorable for earworm control. Husk shortening due to drought, although usually much less severe than in the cases cited, has probably been responsible to a considerable degree for the differences that have been observed in the effectiveness of earworm control by means of an insecticidal oil injected into the silk mass.

SUMMARY

The effectiveness of mineral oil containing insecticides applied to sweet corn ears to control earworms (*Heliothis armigera* (Hbn.)) was variable, even when applied to plantings made from the same lot of seed and grown under similar conditions except planting date. Since characters of the husks were known to influence the severity of earworm damage, measurements were made to determine whether differences in extension of the husk beyond the cob occurred which might be responsible for the variations in control. Ears of Marcross 6.13 were measured in 1939 and ears of Golden Cross Bantam in 1940. In each year some of the plantings had been subjected to severe drought, and in fields so affected the husks of ears were much shorter than usual.

In ears having short husks earworms disperse more rapidly than in normal ears and reach the kernels in positions where the insecticidal oil does not reach them, particularly if the husks are limp and do not press tightly against the kernels, as is the case with drought-affected corn.

It appeared that drought injury to corn in causing stunted husks was a factor determining the variable control that had been observed.

POLLINATION AND SEED FORMATION IN GRASSES[1]

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INTRODUCTION

An understanding of the mode of pollination and seed formation of a species is commonly accepted as fundamental in the initiation of any plant breeding program. The objective of the work reported herein was to obtain such information for a number of exotic and endemic grasses of agronomic interest and importance in the Pacific Northwest. Many of the species reported upon here have been studied only superficially, but until more complete information is available the data may be of use to those concerned with improvement and propagation problems. While strain comparisons were not made, the results for each species represent more than one strain or collection in most instances.

In recent years considerable attention has been given to studies of fertilization and subsequent embryological development of certain grasses. The occurrence of apomixis in some species raises the question whether seed setting under bags should be considered as necessarily identical with self-fertility in the true genetic sense. To answer this question definitely would require cytological and embryological investigations, and in the work here discussed such studies were not made. However, high incidence of seed setting under bags may be considered practically as an approximate criterion of breeding behavior. In this paper the term "fertility" is used only in the sense of seeds developed, with no implication as to whether true fertility existed.

REVIEW OF LITERATURE

Except for certain general relations and methodology, only work pertinent to the fertility of the species under investigation will be reviewed here.

A summary of some of the results of earlier investigations of self-fertility in a number of grass species is presented in table 1. In some instances the reports are based upon observations of flowering rather than upon controlled pollination studies. The data for some species allow considerable variation in interpretation, and the classes as given should be considered as general only. However, as the table indicates, there is essential agreement among the different workers as to relative self-fertility. If heritable plant or strain variations were noted, this fact is indicated. Peto (*24*) [2] reported Malte, Robinson, and Kirk as believing species of *Agropyron* to be highly self-fertilized, and Beddows (*2*) found annual species to be generally highly self-fertile.

[1] Received for publication January 16, 1943. Cooperative investigations of the Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration; Division of Nurseries, Soil Conservation Service, U. S. Department of Agriculture; and the Washington Agricultural Experiment Station, Pullman, Wash.

[2] Italic numbers in parentheses refer to Literature Cited, p. —.

TABLE 1.—*Results of other investigators in self- and cross-fertility studies of certain grass species*

Species	Self-fertility			Heritable plant or strain variation
	High	Intermediate	Low	
Agropyron caninum	[1](2)			
Agropyron cristatum			(31)	(31).
Agropyron elongatum			(1, 11, 30)	(11).
Agropyron intermedium			(30)	
Agropyron repens			(2)	(2).
Agropyron tenerum	(2, 7, 13, 19)			(2).
Arrhenatherum elatius			(4, 5, 29)	(29).
Bromus carinatus	(2)			
Bromus erectus			(2, 16)	
Bromus inermis			(2, 7, 12, 14, 29, 31)	(2, 7, 12, 14, 31).
Bromus madritensis	(2)			
Bromus mollis	(16, 29)			
Bromus secalinus	(2, 16)			
Bromus tectorum	(2, 16)			
Dactylis glomerata	(28)		(4, 5, 7, 16, 18, 20, 27, 29, 32)	(4, 7, 18, 23, 29).
Elymus junceus		(26)		
Festuca arundinacea		(2, 31)	(29)	(2, 31).
Festuca elatior		(2, 16, 31)	(4, 5, 7, 23, 29)	(2, 7, 23, 29, 31).
Festuca ovina			(29)	
Festuca rubra			(8, 16, 22, 23, 29, 31)	(8, 22, 23, 31).
Hordeum bulbosum			(16, 17)	
Phalaris arundinacea			(29)	
Poa compressa	(31)	(29)		
Poa pratensis	(16, 22, 23)	(29)	(5)	(22, 23, 29).

[1] Numbers refer to Literature Cited, p. 16.

Raum (*25*) and Fruwirth (*5*) early recognized the relation of environmental conditions to flowering, pollination, and seed set. Type of inflorescence, covering material, and size of enclosure were given particular attention. Knoll (*15*) found a good negative correlation between humidity and seed set. Beddows (*2*) concluded that some depression of seed set occurred because of bagging. Hayes and Barker (*6*) observed fertility under greenhouse conditions and under field conditions to be positively correlated.

Raum (*25*), in studying some of the problems of technique such as pollination control, compared "pergamine," oil-paper, cotton, and gauze coverings. Fruwirth (*5*) compared pergamine bags and isolation of two or more plants of the same clone together under oilcloth-covered frames, with respect to seeds produced. While the data presented were not for comparable years and the results were variable, oil paper or cloth was preferred to pergamine because of durability. Frandsen (*4*), in tests with pergamine, linen, and glass coverings, found that fewest seeds developed under pergamine. McRostie, as reported by Wolfe and Kipps (*32*), found that cloth cages allowed higher seed set than glassine bags. Knoll (*15*) obtained higher seed set with pergamine than with oil or paraffin paper; the pergamine allowed more light to enter the bag. Jenkin (*10*) secured better results with parchment than with glazed or waxed paper. Beddows (*2*) utilized parchment sleeves or closely woven cloth bags for pollinations out of doors and glazed paper bags in the greenhouse. Nilsson (*23*) used double pergamine bags.

In general Frandsen (*4*) obtained somewhat better seed setting when more than one inflorescence was enclosed in the same bag, although in some instances the differences were slight. Similar results were obtained by Sylven as reported by Nilsson (*23*). Knoll (*15*) found isolation of panicles to be more favorable for seed set than enclosure

of entire plants. Wolfe and Kipps (*32*) obtained higher seed set by covering heads with paper bags than by enclosing entire plants with cloth cages. Clarke (*3*) recognized the possibility that differential reaction to coverings might exist among plants.

Fruwirth (*5*) observed considerable variation in seed setting among different heads of the same plant, and similar observations were made by Clarke (*3*), Hayes and Garber (*7*), and Nilsson (*23*).

Marked interannual variations in the ability of plants to set seed have been reported by Fruwirth (*5*), Frandsen (*4*), Jenkin (*9*, *10*), Nilsson (*23*), and Schultz (*27*). Fruwirth (*5*) and Jenkin (*9*) have also called attention to the inadequacy of single or few tests of self-fertility as a basis for classifying individuals in this respect. Fruwirth has noted large differences among plants of the same clone. Nilsson (*23*) found variation between clonal families to be greater than that within clonal families. He also observed a fair to good relationship between results of pollination of the same plants in different years.

Frandsen (*4*) was one of the earliest workers to report differences in self-fertility among strains of the same species. Similar results were reported by Hayes and Barker (*6*) and Beddows (*2*). Variation within strains in ability to set seed under conditions of selfing has also been noted by several workers. Sylven, cited by Nilsson (*23*), used the highest values obtained as the result most descriptive of true fertility. Nilsson, however, considered the average to be more representative of the individual or strain concerned.

Few reports are available in which the germination of seeds from cross-pollination is compared with that of seeds derived from selfing. Jenkin (*9*) found that seeds from selfed plants germinated poorly as compared with those obtained from cross-pollination, but Wolfe and Kipps (*32*) observed no difference.[3]

MATERIAL AND METHODS

Specific identification of all the species studied was verified in the course of the investigations, during the seasons from 1936 to 1940, inclusive.[4] The close relationship of *Bromus carinatus* Hook. and Arn. to certain other species listed is recognized. An analogous situation may occur in *Poa ampla* Merr. and species similar to it. Numbered strains were used, some being foreign plant introductions and a few derived from commercial sources. Many were collections of native species made in the Pacific Northwest by the Division of Nurseries of the Soil Conservation Service, United States Department of Agriculture, and subsequently propagated at Pullman, Wash. All strains were not studied in all years.

General conditions for flowering and seed setting during the seasons of the investigations appeared to be favorable, though no detailed observations were made of them and brief exceptions may have occurred. Day temperatures rarely reached 100° F., with 65° to 85° common; temperatures at night were low, ranging from 40° to 70°. Humidity was typical of the Columbia Basin area, being generally low during the day and relatively high in very early morning. Moisture conditions were favorable for growth and seed production;

[3] Since the present paper was completed, two new contributions to the literature, by Murphy (*20*) and Myers (*21*), have appeared.

[4] Principally through the cooperation of the Division of Plant Exploration and Introduction, Bureau of Plant Industry, Soils, and Agricultural Engineering.

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occasional rains were interspersed with relatively dry, often clear weather. The average mean-maximum and mean-minimum temperatures and the average precipitation for May, June, and July (1936–40), when flowering and ripening occur, are shown in table 2.

TABLE 2.—*Average mean-maximum and mean-minimum temperatures and average precipitation for May, June, and July, 1936–40*

Item		May	June	July
Temperature:				
Minimum	°F.	43.32	43.97	49.74
Maximum	°F.	69.97	70.53	84.94
Precipitation	inches	1.48	1.28	0.46

The soil upon which the plants were growing was a medium-heavy Palouse silt loam of somewhat depleted fertility but capable of producing 20 to 35 bushels of wheat per acre. Except annuals, all plants utilized for the studies were in the second to fourth growth years. During the period of investigation no insect or disease injuries appeared to be seriously affecting the growth of bagged plants.

The materials used in covering inflorescences were parchment paper, kraft paper, and glassine bags, or tissue-paper wrappings. The parchment paper was used most frequently. The tissue wrappings were used for certain species, as *Agropyron cristatum* and others having dense, spikelike heads; or those, like *Arrhenatherum elatius*, with slender peduncles that are easily broken. Beginning at the wide end of paper cut in a long triangle, and folding the upper corner down, the inflorescence was wrapped snugly toward the base and the lower end was secured by light string. Heads thus wrapped were unsupported. Before anthesis inflorescences were enclosed with only one per bag, a wisp of cotton being inserted at the mouth of the bag and around the culm. This was held in position by the string tying the bag, and all bagged inflorescences were stabilized by tying them to bamboo-cane supports. Coverings were not removed until determination of seed set following harvest. Open-pollinated inflorescences, usually three in number, were used as checks. As a rule five heads per plant were bagged. In some species shattering occurred in many unbagged heads.

The number of florets per head was estimated by approximate counting. The head was then threshed by hand and the resulting mass was examined for seeds, this process being facilitated by the use of reflected light. Heads with broken or otherwise damaged culms were not included.

RESULTS

GENERAL FERTILITY

In table 3 are presented summary data for seed setting of a number of species with which artificial isolations were made under field conditions. The generally low average of seed set in all species is due in part to a high floret count, as all reasonably well developed florets were included and many of those in secondary and tertiary positions often do not produce seeds under ordinary conditions. In some instances the average seed set per floret was greater with self- than with open-pollination. This is believed to be due to shattering of the seeds of the latter class, though it might be due in part

to random fluctuation. One hundred percent is assumed to be the maximum seed set for selfed inflorescences. In several species the selfed seed percentage approached 100, and such species are considered to be highly or completely self-fertile. Such a conclusion may be verified in part if single-plant progenies appear to breed true to the parental type. Table 3, column 5, shows the relative fertility class of the different species on the basis of breeding behavior in tests of progeny uniformity. In a few species the amount of selfed seed is less than would be expected on the basis of self-fertility, but breeding behavior supported the latter classification. To illustrate, progenies of *Poa ampla*, *P. juncifolia*, and *P. nevadensis* appeared to be highly uniform, though large variations occurred in the amount of seed produced.

TABLE 3.—*Relative seed setting of a number of grass species self- and cross-pollinated under field conditions*

[Data from several seasons]

Species	Plants	Average seeds per floret		Self-seed
		Self-pollinated	Cross-pollinated	
	Number	*Number*	*Number*	*Percent*
Agropyron caninum (L.) Beauv	14	0.588	0.735	[1] 80.00
Agropyron ciliare (Trin.) Franch	5	.892	.950	[1] 93.89
Agropyron cristatum (L.) Gaertn	250	.006	.277	[3] 1.99
Agropyron dasystachyum (Hook.) Scribn	4	.011	.172	[3] 6.40
Agropyron desertorum (Fisch.) Schult	5	.006	.579	[3] .97
Agropyron elongatum (Host) Beauv	11	.090	.333	[2] 27.16
Agropyron inerme (Scribn. and Smith) Rydb	45	.018	.286	[3] 6.22
Agropyron intermedium (Host) Beauv	9	.007	.234	[3] 2.99
Agropyron repens (L.) Beauv	10	.005	.248	[2] 2.10
Agropyron sibiricum (Willd.) Beauv	18	.001	.551	[2] .15
Agropyron smithii Rydb	42	.010	.457	[3] 2.08
Agropyron spicatum (Pursh) Scribn. and Smith	51	.015	.294	[3] 5.03
Agropyron trachycaulum (Link) Malte	36	.669	.589	[1] 100.00
Agropyron trichophorum (Link) Richt	35	.012	.227	[3] 5.33
Arrhenatherum elatius (L.) Presl	47	.019	.399	[3] 4.74
Bromus carinatus Hook. and Arn	10	.552	.302	[1] 100.00
Bromus erectus Huds	20	.033	.355	[3] 9.36
Bromus inermis Leyss	199	.028	.375	[3] 7.39
Bromus marginatus Nees	10	.890	.975	[1] 91.28
Bromus polyanthus Scribn	21	.621	.674	[1] 92.13
Dactylis glomerata L	50	.038	.417	[2] 9.21
Elymus angustus Trin	2	.090	.680	[3] 13.24
Elymus canadensis L	17	.599	.943	[1] 63.54
Elymus chinensis (Trin.) Keng	2	.003	.100	[3] 3.30
Elymus condensatus Presl	6	.005	.383	[2] 1.30
Elymus giganteus Vahl	6	.005	.231	[2] 1.92
Elymus glaucus Buckl	19	.661	.629	[1] 100.00
Elymus junceus Fisch	12	.002	.593	[3] .35
Elymus sibiricus L	2	.367	.667	[1] 55.00
Elymus triticoides Buckl	10	.001	.128	[3] .39
Festuca elatior L	9	.034	.171	[2] 20.12
Festuca elatior var. *arundinacea* (Schreb.) Wimm	10	.170	.651	[2] 28.07
Festuca idahoensis Elmer	20	.153	.347	[2] 44.17
Festuca ovina L	17	.025	.284	[3] 8.86
Festuca rubra L	3	.047	.177	[2] 26.57
Hordeum brevisubulatum (Trin.) Link	6	.001	.634	[3] .11
Hordeum bulbosum L	22	.045	.758	[3] 5.92
Koeleria cristata (L.) Pers	15	.001	.279	[3] .21
Oryzopsis hymenoides (Roem. and Schult.) Ricker	14	.284	.427	[3] 5.63
Phalaris arundinacea L	20	.018	.429	[3] 4.29
Phleum graecum Boiss and Heldr	5	.006	.765	[3] .72
Phleum phleoides (L.) Karst	5	.002	.850	[3] .20
Poa ampla Merr	20	.566	.668	[1] 84.76
Poa canbyi (Scribn.) Piper	29	.650	.624	[1] 100.00
Poa compressa L	4	.441	.735	[1] 59.98
Poa juncifolia Scribn	3	.186	.590	[1] 31.47
Poa nevadensis Vasey	6	.283	.509	[1] 55.63
Poa pratensis L	6	.533	.814	[1] 65.48

See footnotes at end of table.

TABLE 3.—*Relative seed setting of a number of grass species self-and cross-pollinated under field conditions*—Continued

Species	Plants	Average seeds per floret		Self-seed
		Self-pollinated	Cross-pollinated	
	Number	*Number*	*Number*	*Percent*
Puccinellia distans (L.) Parl	4	0.029	0.660	[3] 4.38
Puccinellia nuttalliana (Schult.) Hitchc	9	.190	.491	[2] 38.67
Sitanion hystrix (Nutt.) J. G. Smith	6	.396	.823	[1] 48.13
Stipa columbiana Macoun	22	.838	.730	[1] 100.00
Stipa comata Trin. and Rupr	5	.353	.521	[1] 67.78
Stipa lettermani Vasey	2	.606	.554	[1] 100.00
Stipa robusta Scribn	2	.596	.540	[1] 100.00
Stipa viridula Trin	2	.886	.868	[1] 100.00

[1] High self-fertility.
[2] Intermediate self-fertility.
[3] Low self-fertility.

Seed setting under greenhouse conditions was determined for several species as follows:

Species:	*Seeds per floret*
Agropyron caninum (L.) Beauv	[1] 0.878
Agropyron inerme (Scribn. and Smith) Rydb	[3] .014
Agropyron intermedium (Host) Beauv	[3] .133
Agropyron semicostatum (Steud.) Nees	[1] .641
Bromus catharticus Vahl	[1] .971
Bromus commutatus Schrad	[1] .945
Bromus inermis Leyss	[3] .007
Bromus madritensis L	[1] .801
Bromus marginatus Nees	[1] .983
Bromus mollis L	[1] .940
Bromus secalinus L	[1] .610
Elymus canadensis L	[1] .868
Elymus sibiricus L	[1] .749
Elymus virginicus L	[1] .978
Festuca elatior var. *arundinacea* (Schreb.) Wimm	[3] .000
Hordeum brevisubulatum (Trin.) Link	[3] .008
Hordeum jubatum L	[1] .720
Hordeum murinum L	[1] .884
Hordeum nodosum L	[2] .388
Secale montanum Guss	[3] .630
Sitanion hystrix (Nutt.) J. G. Smith	[2] .486

[1] High self-fertility.
[2] Intermediate self-fertility
[3] Low self-fertility.

Single plants were grown in spatial isolation without covering. The results, where comparable, are in general agreement with those for plants grown under field conditions except possibly for *Festuca elatior* var. *arundinacea*. Observations of other plants fruiting in the greenhouse—of which no accurate counts were made—indicated that *Bromus carinatus*, *B. marginatus*, *B. rigidus* Roth., *B. tectorum* L., and *Hordeum nodosum* were also highly self-fertile, although this finding is not in complete agreement with the data shown in table 3 for the last-named species. *Agropyron elongatum* and *Secale montanum* set few seeds, and *Hordeum brevisubulatum* was sterile.

In table 4 distributions into fertility classes have been made for plants studied under field conditions. In many instances but few individuals were observed, and distributions for such species may have comparatively little significance. The table includes only those species of which nine or more plants were studied.

TABLE 4.—*Comparison of self- and open-pollinated progenies in distribution of plants in fertility classes based upon several years' results*

Species	Pollination	Plants setting indicated number of seeds per floret																					Total plants
		0.00	0.025	0.075	0.125	0.175	0.225	0.275	0.325	0.375	0.425	0.475	0.525	0.575	0.625	0.675	0.725	0.775	0.825	0.875	0.925	0.975	1.000	
		No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.
Agropyron caninum	S	1		1	2									1	1			1	3	2	2			14
	O					2		1		1							1	1	2	1	2	2	1	14
Agropyron cristatum	S	92	141	6	4	2				2	1		1	1										250
	O	33	22	18	22	29	18	14	16	18	17	11	15	9	4	1	1			2				250
Agropyron elongetum	S	3	1	1		2		1		2		1												11
	O						1		1	2	2	1	2		1	1								11
Agropyron inerme	S	19	20	4		1									1									45
	O		5	6	6	8	2	4	4	1	1	2		2	1		1	2						45
Agropyron intermedium	S	1	8																					9
	O		1			3	1	1	2		1													9
Agropyron repens	S	6	3	1																				10
	O			2	2	1			1	1				1	2									10
Agropyron sibiricum	S	14	4																					18
	O									1	1	4	2	4	2	2	1						1	18
Agropyron smithii	S	14	24	3											1									42
	O	1	1		2		5	2	4	2	7	5	2	2	5	1	1	2						42
Agropyron spicatum	S	25	20	4	2																			51
	O		7	7	8	1	4	2	4	7	3	2		1	1	1				2		1		51
Agropyron trachycaulum	S	1		1	4	3	4	3	5	2	7		3	1					2					36
	O				4	1	5	7	6	4	4	1	1	1	1			1						36
Agropyron trichophorum	S	18	15		1	1																		35
	O		3	5	3	8	5	2	1	1	1	1	2	3										35
Arrhenatherum elatius	S	6	34	6	1																			47
	O		1		4	10	2	3	5	2	2	1	5	2	1	3	2	1	2	1				47
Bromus carinatus	S							1		1	1	1	2	2			2							10
	O					1		5	1	3														10
Bromus erectus	S		13	3	2	1																		19
	O					2	1	1	4	2	4	2		1	1				1					19
Bromus inermis	S	40	126	17	7	4	1	3	1															199
	O		3	8	14	13	11	17	14	26	24	13	27	6	10	7	1	3	1	1				199
Bromus marginatus	S																	1	1			8		10
	O										1		2	1				1		1		4		10
Bromus polyanthus	S									1	1	2	3	3	3			3	2			3		21
	O					1	1		1		1	1	2	2		2		4	1	3	2			21
Dactylis glomerata	S	10	30	7			1			1	1													50
	O		1		2	1	2	1	9	5	5	4	8	3	2	4	1				2			50
Elymus canadensis	S								2		2	2	2	2		2	2	1				1	1	17
	O															1	1			1	2	2	10	17
Elymus glaucus	S		2			1		3		3				1	1		3		1	1			3	19
	O								1	3	1	1			1	5	3			1	2		1	19
Elymus junceus	S		12																					12
	O							1				1	1	1	3	2	1	1	1					12

TABLE 4.—*Comparison of self- and open-pollinated progenies in distribution of plants in fertility classes based upon several years' results*—Con.

Species	Pollination	Plants setting indicated number of seeds per floret																						Total plants
		0.00	0.025	0.075	0.125	0.175	0.225	0.275	0.325	0.375	0.425	0.475	0.525	0.575	0.625	0.675	0.725	0.775	0.825	0.875	0.925	0.975	1.000	
		No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.
Elymus triticoides	S	8	2																					10
	O		1	1	5	2			1															10
Festuca elatior	S		4	5																				9
	O						7	2																9
Festuca elatior var. *arundinacea*	S	2	1	5				1							1									10
	O											1		1	1	1	1		1		1	2	1	10
Festuca idahoensis	S		3	5	3	2	1	1		3	1	1												20
	O		2	1		1	2		1	2	2	2	2	1		1		2				1		20
Festuca ovina	S	5	10	1	1																			17
	O		1	3	3	1	2	2	1		1		1			1							1	17
Hordeum bulbosum	S	7	6	6	2		1																	22
	O											1		1	3	2		4	7	4				22
Koeleria cristata	S	9	6																					15
	O				2	1	2	3	5			1	1											15
Oryzopsis hymenoides	S	1	6	2		1			3	1														14
	O				1	6	1					2	1				1	1			1			14
Phalaris arundinacea	S		19				1																	20
	O				1	2	2	1		1		3		1	1	5	2	1						20
Poa ampla	S				2	2	5	1	1		1					2	1	2		3				20
	O								3	3	2	3	1	1	2		1	1	3					20
Poa canbyi	S		1		1	2			1	2	1	1	1	1	1				1	6	6	1	3	29
	O							1	1	1	2	1	2	4	1	2	3	2	3	2	1	1	2	29
Puccinellia nuttalliana	S	5	2							1													1	9
	O			1			1					1		2		1						2	1	9
Stipa columbiana	S										1			1			1	2	3	8	3	3		22
	O											1		4	2	1	6			3	5			22

Among species previously classified as highly self-fertile, *Agropyron caninum*, *A. trachycaulum*, *Elymus canadensis*, *E. glaucus*, *E. sibiricus*, *Poa ampla*, *P. canbyi*, *P. compressa*, *P. juncifolia*, *P. nevadensis*, *P. pratensis*, and *Stipa comata* included some plants lower in self-fertility than might have been expected. It should be noted, however, that few plants of some of these species were studied. In species with low average self-fertility the distribution of individual plant values is well concentrated in lower classes. In *Bromus inermis*, *Dactylis glomerata*, and *Oryzopsis hymenoides* more variation occurred among individual plants. Although plants of most species having a low average self-fertility were well grouped, occasional medium-fertile individuals occurred. This may be seen for *Agropyron cristatum*, *A. inerme*, *A. smithii*, *Dactylis glomerata*, and *Oryzopsis hymenoides*. In these experiments, species of most uniformly low self-fertility were *A. sibiricum*, *Elymus junceus*, *E. triticoides*, *Hordeum brevisubulatum*, *Koeleria cristata*, and *Phleum phleoides*.

SEASONAL AND OTHER RELATIONS

Table 5 includes data for seed setting with and without parchment-paper bags for the same plants of four species observed in several years. Great differences are apparent when results for different species, self- and open-pollination, and different years are compared. A summary was made of the regularity of zero seed set, based upon other data of *Agropyron cristatum*, *Bromus inermis*, and *Dactylis glomerata* when selfed for several years. Plants giving zero seed set in 1 year showed a strong tendency to continue to fail to produce seed, though many exceptions occurred. The comparisons of plant behavior from year to year among individuals of low self-fertility indicate the relative stability of this character to be good from season to season.

Attempts were made to correlate the results for successive years in seed setting with self- and open-pollination in several species. These results were derived from data from 35 plants of each of 6 species. Plants failing to produce seed when selfed or open-pollinated were not included. The relations of selfed seed percentages as obtained for the same plants in 2 different years are given in table 6.

TABLE 5.—*Interannual variation of seed setting of individual selected plants with self- and open-pollination*

AGROPYRON CRISTATUM

Plant No.	Average seeds per floret							
	Open-pollinated				Selfed			
	1937	1938	1939	1940	1937	1938	1939	1940
	No.	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*
H4–1	0.06	0.14	0.34	0.10	0.005	0.000	0.004	0.003
H13–3	.22	.24	.37	.....	.000	.000	.002	.....
H14–2	.55	.49	.52	.....	.003	.020	.004	.....
H16–2	.25	.19	.16	.....	.003	.000	.002	.....
H17–2	.005	.01	.00	.....	.000	.000	.000	.....
H17–3	.16	.12	.10	.....	.000	.000	.007	.....
H19–1	.12	.25	.17	.....	.000	.000	.001	.....
H21–2	.17	.43	.21	.58	.005	.001	.000	.120
H22–2	.19	.30	.24	.....	.000	.002	.002	.....
H26–2	.01	.04	.01	.....	.000	.000	.000	.....

TABLE 5.—*Interannual variation of seed setting of individual selected plants with self- and open-pollination*—Continued

ARRHENATHERUM ELATIUS

Plant No.	Average seeds per floret							
	Open-pollinated				Selfed			
	1937	1938	1939	1940	1937	1938	1939	1940
	No.	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*
12	0.38	0.14	0.19	0.47	0.020	0.007	0.010	.....
18	.26	.12	.67	.....	.040	.060	.026	.....
26	.50	.18	.73	.....	.007	.060	.008	.....
31	.40	.16	.80	.....	.080	.010	.004	.....
38	.34	.16	.39	.....	.040	.002	.010	.....
50	.58	.18	.50	.....	.007	.020	.009	.....
55	.54	.18	.67	.....	.020	.060	.001	.....
61	.54	.14	.74	.58	.000	.000	.001	0.005
80	.82	.20	.75	.....	.014	.000	.007	.....
86	.16	.16	.67	.....	.040	.014	.005	.....

BROMUS INERMIS

	1936	1937	1938	1939	1936	1937	1938	1939
88	0.12	0.32	0.34	0.48	0.000	0.000	0.001	0.000
90	.16	.26	.19	.27	.001	.000	.000	.000
91	.14	.40	.49	.42	.016	.100	.006	.017
92	.16	.58	.53	.38	.000	.060	.004	.000
93	.06	.58	.68	.33	.006	.008	.006	.000
94	.14	.38	.44	.39	.120	.032	.008	.005
95	.10	.50	.18	.28	.002	.002	.000	.000
96	.06	.40	.70	.50	.000	.016	.026	.006
100	.10	.24	.16	.23	.006	.004	.002	.000
102	.08	.44	.38	.43	.002	.000	.030	.049

DACTYLIS GLOMERATA

11	0.20	0.56	0.42	.....	0.000	0.000	0.030
29	.40	.57	.67	.....	.020	.035	.070
31	.17	.52	.69	.....	.003	.000	.030
38	.56	.68	.49	.....	.002	.000	.030
51	.43	.50	.49	.....	.005	.007	.020
63	.30	.35	.53	.....	.020	.005	.080
65	.30	.36	.39	.....	.410	.042	.050
72	.37	.54	.31	.....	.001	.000	.004
77	.31	.54	.51	.....	.070	.000	.010
93	.33	.41	.46	.....	.050	.000	.090

TABLE 6.—*Percentages of seed obtained from the same self-pollinated plants in different years*

Species	*r*	*P*
Agropyron cristatum	0.50	>0.01
Agropyron inerme	.00	.....
Arrhenatherum elatius	.42	>0.05
Bromus inermis	—.04	(1)
Dactylis glomerata	.07	(1)
Poa ampla	.44	(1)

[1] Insignificant.

Of the species listed, *Poa ampla* is considered to be highly self-fertile. When seed setting with open-pollination was compared in consecutive years, significant agreements were indicated for *Arrhenatherum elatius*

and *P. ampla*. Insignificant *r* values were obtained for *Bromus inermis* and *Dactylis glomerata*. When results in seed setting from self- and open-pollination were compared for the same season, negative correlations were obtained for *Agropyron cristatum*, *Arrhenatherum elatius*, *Bromus inermis*, and *Dactylis glomerata*. That for *A. elatius* was highly significant, *P* values for the others not reaching the 0.05 point.

While data were available for other species, these were generally insufficient to permit comparable analyses. The point of principal interest in the results presented is a frequent failure in close agreement of results in different seasons.

In *Agropyron cristatum* and *Bromus inermis*, where data were available for more plants, the chi-square test for independence was utilized to study the relation of self- and cross-fertility. In this test plants failing to set seed when selfed but which were cross-fertile were included. The results are given in table 7.

TABLE 7.—*Statistical analysis of data on relation of self- and cross-fertility*

Species	Plants	Degrees of freedom	χ^2	*P*
	Number			
Agropyron cristatum	294	12	56.04	>0.01
Bromus inermis	207	9	34.61	>.01

The analysis indicates that self- and cross-fertility are unquestionably interrelated in a positive manner in these species.

Coefficients of variability indicated that plant variation in seed setting was much greater with self- than with open-pollination, as might be expected. The variation was not closely similar for all species or in all seasons. Neither did variability in seed setting always move in the same direction from season to season when results from self- and open-pollination for the same plants were compared.

It should be noted that in the previous discussion, with some exceptions, plants failing to set seed in any year have been omitted from consideration. While this procedure may be somewhat arbitrary, since by random chance some partly fertile plants may fail to set seeds, a classification is required. Percentages of self-sterile plants for several species were as follows: *Agropyron cristatum*, 36.8; *Arrhenatherum elatius*, 13.0; *Bromus inermis*, 16.0; and *Dactylis glomerata*, 20.0.

Eighteen species, principally of *Agropyron* but including others, of which more florets were counted, were studied for relative seed set under different types of covering. Considering all 18 species, seed set was highest under parchment-paper bags in 1 of 2 comparisons. In comparisons of tissue wrappers and glassine bags, the latter gave the higher results in 9 comparisons, and the former in 4; in 4 the results were similar.

Comparisons between parchment- and kraft-paper bags for covering were made with *Bromus inermis*, sister clones being used as replicates. The results are given in table 8.

TABLE 8.—*Relative seed set with parchment- and kraft-paper bags for coverings*

Covering	Florets	Seeds	Average seeds per floret
	Number	*Number*	*Number*
Parchment	11,659	107	0.009
Kraft	12,181	32	.003

The seed set under parchment-paper bags exceeded that under kraft-paper bags in 14 of 16 plants studied. In another season, seed set in glassine bags exceeded that in parchment-paper bags in 12 of 21 trials, results with parchment paper exceeding those with glassine but 4 times. In some instances intraclonal variation was as high as 900 percent. In earlier investigations parchment paper was generally superior to kraft paper or glassine as a covering in tests with many species.

A limited number of studies were made to determine the seed development in *Bromus inermis* where 1 or more than 1 inflorescence was enclosed in each parchment-paper bag. The results are summarized in table 9. Evidently humidity or such other effects as may result from placing 2 or more heads in 1 bag had no important influence on seed setting in *B. inermis* under the conditions of this experiment, though averages suggest differences in favor of more panicles up to 5 being enclosed in each bag. In counting the possible comparisons, the average of 2 or more panicles exceeded that of 1 in seed set 36 times, was exceeded by one 32 times, and was the same 8 times.

TABLE 9.—*Comparison of seed setting in Bromus inermis with 1 or more than 1 panicle enclosed in each bag, 1940*

Panicles enclosed (number)	Total florets	Total seeds	Average seeds per floret
	Number	*Number*	*Number*
2	565	70	0.124
1 [1]	285	15	.053
3	3,991	285	.071
1	1,480	50	.034
4	21,081	779	.037
1	5,919	127	.021
5	16,619	424	.026
1	4,068	258	.063
Total or average:			
More than 1 panicle enclosed	42,256	1,558	.037
1 panicle enclosed	11,752	450	.038

[1] Check for number above.

Germination percentages of seeds resulting from self-pollination and open-pollination in 3 years have been summarized for some species in table 10. Germination from self-pollination exceeded that from open-pollination twice in 1936, 7 times in 1938, and once in 1939, for a total of 10 in 30 comparisons. Differences within species were inconsistent. In general the data indicate that selfed seeds may not germinate so well as those from open pollination. It should be noted that the species listed are from the group of low self-fertility, as self-fertile species might be expected to germinate equally well from selfed or open-pollinated seed.

TABLE 10.—*Summary of germination percentages of seeds of species self-pollinated and open-pollinated in several years*

Species	Seeds germinated from self-pollination or open pollination							
	1936		1938		1939		Average	
	Self	Open	Self	Open	Self	Open	Self	Open
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Agropyron cristatum	33.4	41.1	56.6	37.8	47.1	55.6	45.7	44.8
Agropyron inerme	54.6	71.1	53.1	50.3	67.8	68.0	58.5	63.1
Agropyron smithii	91.7	63.0	85.7	32.3	43.2	53.0	73.5	49.4
Agropyron spicatum	61.0	67.7	38.8	43.2	72.3	80.7	57.4	63.9
Agropyron trichophorum	47.1	59.4	53.8	23.9	9.3	22.2	36.7	35.2
Arrhenatherum elatius	60.7	48.1	44.4	89.6	11.5	20.7	38.9	52.8
Bromus erectus	-------	-------	26.0	26.8	77.5	75.5	51.8	51.2
Bromus inermis	58.9	65.5	29.6	22.2	50.7	77.6	46.4	55.1
Dactylis glomerata	-------	-------	24.2	21.9	10.1	34.8	17.2	28.4
Hordeum bulbosum	-------	-------	59.4	41.8	24.7	51.4	42.1	46.6
Phalaris arundinacea	43.6	82.6	5.8	14.6	36.9	47.0	28.8	48.1
Average	56.4	62.3	43.4	36.8	41.0	53.3	45.2	49.0

DISCUSSION

Nilsson (*23*) presented a thorough discussion of the numerous factors and relationships involved in self-fertility studies of grasses. The writer is in general agreement with his conclusions and viewpoint.

The conditions under which the present work was done were considered to be generally favorable for seed setting. This conclusion is based to a large extent upon the fact that under conditions at Pullman, Wash., practically all grass species show a high degree of fertility under field conditions and seed yields are very good. It is admitted, however, that short periods unfavorable to seed setting might markedly affect the results with specific strains. The possible effects of bringing together a number of ecological strains of a species or species complex and studying these under one environment should also be recognized, for such strains might be modified differentially in fertility as well as in other characters.

The low average fertility values presented may be attributed to high estimates of floret numbers, since all reasonably well developed flowers were counted. In self-fertile species practically all of the primary florets developed seeds. Beddows (*2*) reported, however, that empty florets were not restricted to any part of the inflorescence.

The data presented will allow the reader to arrive at his own conclusions as to the self-fertility of the species studied. Rogler (*26*) reported *Elymus junceus* to be of intermediate self-fertility, whereas very few selfed seeds were obtained for this species in these experiments. *Agropyron elongatum* and *Festuca rubra* were reported by others to have low self-fertility, whereas they were found to be somewhat intermediate in the present investigations. The results with *Poa pratensis* were in agreement with those of Nilsson (*23*). It is possible that apomixis may be concerned in seed formation in species other than *Poa pratensis*, where it is known to occur commonly. With results for all other species previously studied the work reported here was in agreement.

The self-fertility studies have served to verify, in the main, the conclusions reached by observing breeding behavior, namely, that

a number of native species in the Pacific Northwest are highly self-fertile. Since these occur widely throughout the area, collection of types from local habitats [5] has brought together numerous varieties that may be expected to breed true or practically so. Such have been the results in trials thus far. Classification of other species of intermediate or low self-fertility will serve to aid in the development of suitable breeding and propagation systems where these species are of interest. However, it has been observed that native collections of some species such as *Agropyron inerme* and *A. spicatum* show unexpected uniformity in plant rows if high self-sterility is assumed. This is particularly noticeable in early years of propagation from native sources and may be due in part to the relative uniformity of ecotypes, though cross-pollination may occur within the type. Intertype sterility may also account, in part, for the tendency toward preservation of relative uniformity in some strains.

Considering all plants of *Agropyron cristatum* and *Bromus inermis* studied, self- and cross-fertility appeared to be positively related, while the negative relation in *Arrhenatherum elatius* was hardly expected. Nilsson (*23*) found variations in self-fertility to be positively related to general fertility and discussed the reasons why this might occur. Some types of self-fertility were shown to be independent of general fertility.

Parchment-paper bags were considered to be most satisfactory for controlling pollination, though advantages in seed setting were not great or entirely consistent. In many highly self-fertile species bagged heads set fewer seeds than those unbagged, suggesting the presence of some detrimental influence due to bagging.

Nilsson (*23*) pointed out that true self-fertility is probably somewhat higher than that indicated in controlled-pollination tests. This would appear to be a justifiable conclusion, since enclosure of flowers might ordinarily be detrimental to seed setting, as suggested by Raum (*25*), Fruwirth (*5*), Knoll (*15*), and others. Until such conditions can be compensated for, it would appear that average seed set would be most descriptive of the species if based upon a reasonably large number of plants. Knowledge of the distribution of these in the range of fertility is also important, however.

Prominent variations in results obtained from year to year would render questionable any effort to classify plants narrowly as to self-fertility. Fluctuations among inflorescences of the same plant and significant differences among clones from the same plant serve to emphasize the difficulty of differentiating between plants. Similarly, small differences between strains might be of questionable significance. Frequent occurrence of zero seed set in one or more bags, where other bagged heads of the same plant may give few to fairly numerous seeds, makes statistical study very difficult if not impracticable.

The studies of the relation of number of inflorescences per bag to seed setting did not indicate any significant differences to exist when one or several heads were enclosed within one covering. This does not support the observations of Frandsen (*4*) or those of Sylven, cited by Nilsson (*23*). However, since the conditions of study and the species observed by Frandsen and Sylven were different from those in the investigation reported here, comparison may not be justified.

[5] Principally by the Division of Nurseries, Soil Conservation Service.

Results of germination tests of seeds from self- and open-pollination are in general agreement with those of Jenkin (*9*), which indicated selfed seeds to have a somewhat lower germination percentage than those derived from open-pollination. Differences were not consistent, however.

SUMMARY

Results of controlled pollination studies of a number of grass species grown under field and greenhouse conditions are reported.

The following species set seed freely when inflorescences were enclosed: *Agropyron caninum, A. ciliare, A. semicostatum, A. trachycaulum, Bromus carinatus, B. catharticus, B. commutatus, B. madritensis, B. marginatus, B. mollis, B. polyanthus, B. rigidus, B. secalinus, B. tectorum, Elymus canadensis, E. glaucus, E. sibiricus, E. virginicus, Hordeum jubatum, H. murinum, Poa ampla, P. canbyi, P. compressa, P. nevadensis, P. pratensis, Sitanion hystrix, Stipa columbiana, S. comata, S. lettermani, S. robusta,* and *S. viridula.*

The following species were intermediate in seed setting when selfed: *Agropyron elongatum, Festuca elatior, F. elatior* var. *arundinacea, F. idahoensis, F. rubra,* and *Poa juncifolia.* Results for *Hordeum nodosum* and *Secale montanum* were inconclusive.

The following species produced very few seeds when subjected to self-pollination: *Agropyron cristatum, A. dasystachyum, A. desertorum, A. inerme, A. intermedium, A. repens, A. sibiricum, A. smithii, A. spicatum, A. trichophorum, Arrhenatherum elatius, Bromus erectus, B. inermis, Dactylis glomerata, Elymus angustus, E. chinensis, E. condensatus, E. giganteus, E. junceus, E. triticoides, Festuca ovina, Hordeum brevisubulatum, H. bulbosum, Koeleria cristata, Oryzopsis hymenoides, Phalaris arundinacea, Phleum graecum, P. phleoides, and Puccinellia distans.*

Field results based upon inflorescences enclosed in bags were generally comparable to those obtained under greenhouse conditions, from isolation of individual plants without bagging.

In most species studied there was considerable variation in both self- and cross-fertility among different plants. Some highly self-sterile species included plants that were sterile also when open-pollinated. Plant variation in seed setting was much greater with self-pollination than with open pollination.

Much random variation occurred in seed setting following self-pollination and open-pollination. Simple explanations of such results were not possible. Interannual fluctuations likewise were great when the same plants were studied in successive years. Classification of plants into narrow groups on the basis of self-fertility appeared to be unwarranted.

Where reliable comparisons were possible, self- and cross-fertility appeared to be positively related in *Agropyron cristatum* and *Bromus inermis,* whereas for *Arrhenatherum elatius* a negative association was indicated.

Differences in seed setting due to the type of paper covering used were generally insignificant. The number of inflorescences enclosed in each bag did not influence the percentage of seeds produced by *Bromus inermis.*

Germination of seeds from self-pollination was slightly inferior to that from open-pollination, though the differences were not consistent.

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